Investigating carbon rationing as a policy for reducing carbon dioxide emissions from UK household energy use

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Doctoral Thesis

2005

Abstract

The central aim of this thesis is to identify a route to achieve 60% carbon savings in the UK domestic sector by 2050. This has led to two key questions:

- Is a strategy of relying largely on improvements in energy efficiency likely to achieve the required savings?
- If not, could personal carbon rations offer an alternative route?

To answer the first question, both the past record and future projections of savings from energy efficiency are investigated. Thirty years of energy efficiency improvements have led to an increase of a third in final energy use, due to a contemporaneous increase in demand for energy services. A bottom-up energy model shows that even modest social and behavioural changes could lead to a future increase in energy consumption of 23% by 2050. In combination with these demand increases, even maximum implementation of energy efficiency measures could only deliver a 17% saving. Policies for improving energy efficiency do nothing to restrain demand for energy services, and this makes it very unlikely they, alone, can deliver 60% carbon savings by 2050.

This thesis proposes that personal carbon rationing, for household and personal transport energy, would provide a framework for guaranteed and equitable carbon reductions, within a context of global carbon reductions. Each person would get an equal ration which would reduce over time. Equal carbon rations would not affect everyone equally because emissions currently vary considerably between groups and individuals. Personal carbon emissions for 32 case study individuals varied by a factor of 12. Therefore a variety of responses to rationing will be required, and energy efficiency will remain an important strategy within the rationing framework. It is concluded that personal carbon rations have considerable promise for achieving 60% savings by 2050.

Acknowledgements

First of all I would like to sincerely thank my supervisor, Professor Tadj Oreszczyn, for his encouragement, constructive advice and helpful support throughout my time of study, and particularly for the 'downhill slope' metaphor after I had completed my first draft.

Working with Mayer Hillman on writing a book in parallel with my PhD research was a great experience, his passion and enthusiasm for taking effective action on climate change has been inspirational, and I have gained from his great knowledge of the field.

Thanks are also due to all the people who filled in carbon audit forms to help with my research, and special thanks to my Mum who persuaded and helped a number of friends and family members to take part.

I am grateful to my whole family for moral and practical support during my return to student life, and to my Dad for the laptop.

Finally, I would like to thank my husband, Richard, for his insightful comments, generous enthusiasm and for patiently listening to far too much energy and climate change talk over the past three years. This PhD is dedicated to him.

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Glossary

Carbon equivalent or Ce is a unit into which greenhouse gases other than carbon dioxide are converted so that they can be compared.

Combi boiler is a boiler with a second heat exchanger which works as an instantaneous water heater.

Energy services are the actual services for which energy is used, e.g. heating a given amount of space to a standard temperature for a period of time.

Final energy, also known as delivered energy, is the energy consumed by final users. It is therefore net of fuel industry own use and conversion, transmission and distribution losses, but includes conversion losses of final users. It is the energy use as metered at the doorstep of a building. This is the measure of energy which will be most commonly used in this thesis.

Household energy use, also known as domestic energy use, is the energy used within households for space and water heating, lighting, cooking and appliances. It does not include personal transport energy use or the embodied energy contained within household goods.

Primary electricity is that obtained other than from fossil fuel sources, e.g. nuclear, hydro, wind and other non-thermal renewables. For electricity not generated from fossil fuels or other combustible fuels, conventions are needed to define primary energy content. For electricity generated from hydro and wind, primary energy equals final energy. For nuclear energy, primary energy is defined as the heat in the steam at the nuclear plant, before it is transformed into electricity (with an average efficiency of 38.05% in 2003 (DTI 2004a)).

Primary energy is a measure of the energy content of primary fuels plus primary electricity. Primary fuels are those obtained directly from natural sources, e.g. coal, oil and natural gas. Primary energy includes energy used or lost in the conversion of primary fuels to secondary fuels (for example in power stations), energy lost in the distribution of fuels (for example in transmission lines) and energy conversion losses by final users.

Radiative forcing is the change in average net radiation at the top of the lower atmosphere which occurs because of a change in the concentration of a greenhouse gas or because of some other change in the overall climate system. A positive radiative forcing tends on average to warm the earth's surface and a negative radiative forcing tends on average to cool the surface.

Useful energy is that energy available after deduction of the losses incurred when final users convert energy supplied into space or process heat, motive power, light or other energy services.

U-value expresses the rate of thermal conduction across a complete building element. Thus U-value is a measure of insulating performance, where lower numbers indicate greater resistance to heat transfer, i.e. better insulation. It is measured in W/m^2K.

Abbreviations

BRE	Building Research Establishment
DEFRA	Department for Environment, Food and Regional Affairs
DETR	Department of Environment, Transport and the Regions
DfT	Department for Transport
DJ-BAU	David Johnston's Business as Usual scenario
DJ-DS	David Johnston's Demand Side scenario
DTI	Department of Trade and Industry
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MtC	Millions of tonnes of carbon dioxide, measured as carbon
MtCe	Millions of tonnes of carbon dioxide equivalent, measured as carbon
ODPM	Office of the Deputy Prime Minister
SDC	Sustainable Development Commission
TF-BAU	Tina Fawcett's Business as Usual scenario
TF-HighE	Tina Fawcett's High Energy scenario
TF-LowE	Tina Fawcett's Low Energy scenario

Chapter 1: Introduction

1.1 Chapter overview

This chapter provides the context for undertaking the thesis research. The importance of climate change as a global environmental problem is established. The current and expected future effects in the UK and world-wide are summarised. The global response to the threat of further climate change is outlined, and this is contrasted with the climate change science indicating the scale of action required. Following this, the aims of the thesis are described and the scope is established. A chapter-by-chapter summary and thesis overview diagram clarifies the overall structure and direction. Finally a methodological overview of the thesis is presented, explaining the research approaches taken overall and in each chapter.

1.2 Context: Insufficient action in the face of climate change

There can be little doubt that climate change is the most important environmental problem facing the world community. This assessment is shared by many people including Sir John Houghton, former head of the Met Office and former co-chair of the Intergovernmental Panel on Climate Change's science working group, who has called climate change a "*weapon of mass destruction*" (Houghton 2003). The Prime Minister has identified climate change as "*unquestionably the most urgent environmental challenge*" (Blair 2003). The UK government's chief scientist, David King, has gone even further, saying: "*climate change is the most severe problem that we are facing today - more serious even than the threat of terrorism*" (King 2004). However, as this section briefly outlines, and as Chapter 2 will further illustrate, the seriousness of the threat of climate change has not been matched by equally serious action to reduce the risk of additional anthropogenic changes in climate either at a global or national level.

1.2.1 Climate Change: the effects to date

The climate is changing because the natural mechanism known as the 'greenhouse effect', which acts to warm the earth, is being increased by anthropogenic emissions of greenhouse gases. The increase in greenhouse gases reduces the efficiency with which the earth's surface radiates energy to space. Change in the net radiative energy available to the global earth-atmosphere system is termed radiative forcing. The current positive radiative forcing tends to warm the earth's surface.

Globally, and for the UK, carbon dioxide is the most significant human-influenced greenhouse gas. Worldwide, carbon dioxide contributes 60% of the radiative forcing from the changes in the concentrations of the key greenhouse gases[1] (IPCC 2001a). Around three-quarters of global carbon dioxide emissions over the past twenty years have come from fossil fuel burning, with the remainder being due to land use change, especially deforestation (IPCC 2001a). In the UK, carbon dioxide is a more significant proportion of national greenhouse gas emissions than the global average, accounting for 80% of the total (DETR 2000a). In addition, in the UK land use change only accounts for 3% of carbon dioxide emissions, the remaining 97% being from fossil fuel burning. Thus, just less than 80% of the UK's contribution to radiative forcing and subsequent climate change comes from burning fossil fuels.

In addition to carbon dioxide, there are five other greenhouse gases which have been included in international negotiations: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. The most significant of these are methane and nitrous oxide. Methane emissions come primarily from agriculture, waste, coal mining and natural gas distribution. Nitrous oxide is generated from agriculture, industrial processes and fuel combustion (DETR 2000a). The other greenhouse gases are emitted from a small range of industrial processes and products. With the exception of methane, these other gases are much easier to control through technological change than is carbon dioxide. These gases are not the subject of this thesis, which will concentrate solely on carbon dioxide emissions from fossil fuel burning.

The evidence for increased concentrations of carbon dioxide (CO_2) in the atmosphere is incontrovertible, and the impacts on climate are becoming increasingly clear. The atmospheric concentration of CO_2 increased from 280 parts per million (ppm) in 1750 to 376 ppm in 2003 (Keeling & Whorf 2004). This is an increase of 34% since 1750. Today's CO_2 concentration has not been exceeded in the past 420,000 years and is likely not to have been exceeded during the past 20 million years (IPCC 2001b). IPCC also found that the rate of increase of carbon dioxide in the atmosphere over the past century is unprecedented at least during the past 20,000 years.

As a result of greenhouse gas emissions, global temperature over land and sea has risen by about 0.6°C (± 0.2°C) since the beginning of the twentieth century (IPCC 2001b, EEA 2004). Furthermore, temperatures on land have warmed more than the oceans. So, for example, central England temperatures rose by almost 1°C in the twentieth century and the 1990s was the warmest decade in central England since records began in the 1660s (Hulme, Turnpenny, & Jenkins 2002). In the summer of 2003, a new temperature record of 38.5°C was set in the UK (Met Office 2004). This was part of a wider European heat wave, which caused an estimated 35,000 deaths (EEA 2004), about 14,000 of those being in France and 2,000 being in the UK

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[1] These are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

(UNEP 2004). It is not possible to attribute this extreme event definitively to climate change, because climate extremes happen naturally by chance. However, it has been estimated that the risk of such a heat wave occurring has been doubled by anthropogenic climate change (Stott et al. 2004).

Rising temperatures have not been the only consequence. There is strong UK evidence for changing rainfall patterns and extremes of climate. For example, winters over the past 200 years have become wetter relative to summers throughout the UK and a larger proportion of winter precipitation in all regions now falls on heavy rainfall days than was the case 50 years ago (Hulme, Turnpenny, & Jenkins 2002). Within Europe the number of disastrous weather or climate-related events per year doubled over the 1990s compared with the previous decade. Four of the five years with the greatest economic losses have occurred since 1997, and losses in an average year cost 10 billion Euros (EEA 2004).

1.2.2 Climate change: future prospects

The most authoritative global projections of future climate change are provided by the Intergovernmental Panel on Climate Change (IPCC). IPCC also provides the leading scientific, economic and social assessments of climate change and its consequences. Their latest projection is that the average surface temperature over land and sea is likely to increase by between 1.4 and 5.8°C by 2100 from 1990 temperatures, and that nearly all land areas are likely to warm by more than this average (IPCC 2001b). This temperature range is broad because it covers various possible economic, social and technical scenarios, each of which results in differing emissions of greenhouse gases. Higher emissions will lead to higher temperatures. The likely effects on humans and the natural environment of high emissions scenarios range from the death of coral reefs (Radford 2001) and extinction of species (Norris, Rosentrater, & Eid 2002, Thomas et al. 2004) to the creation of millions of environmental refugees (Conisbee & Simms 2003). Many countries will be under threat from rising sea levels, drought, storms, heat waves and extreme economic and social disruptions. Sea level is predicted to rise by up to a metre over the current century. This could, for example, lead to a loss (via inundation) of over 20% of Bangladesh's land area, where an eighth of the population currently live (IPCC 2001b). The consequences of allowing the higher emissions scenarios to become reality are global, highly damaging and almost unthinkable.

Changes in the UK will not be as severe as in some other areas of the world. However they will be enough to completely change the experience of living in Britain and to require changes in many aspects of the economy. The degree of change will depend on the emission scenario. By the 2080s, under all emissions scenarios, the climate will be warmer, wetter in winter and drier in summer (Hulme, Turnpenny, & Jenkins 2002). This research also showed that a day-time summer temperature might be expected to exceed 42°C in lowland England once a decade by the 2080s. In addition, snowfall amounts will decrease throughout the UK; by the 2080s large areas of the UK are likely to experience quite long sequences of snowless winters. Some climate change experts predict that the Scottish ski industry will cease to exist within 20 years (Seenan 2004). The number of people at high risk from river and coastal flooding could increase from 1.6 million today to between 2.3 and 3.6 million by the 2080s (Office of Science and Technology 2004). Initial calculations for the Association of British Insurers suggested that climate-related property insurance claims could be two to three times higher in 2050 than at present (Dlugolecki 2004). The research also identified a risk that the frequency and seriousness of extreme weather events might reach a point where property-related insurance could become unaffordable or unavailable. The Department of Health has predicted that health effects would include the re-introduction of malaria and an additional 2,000 deaths per year from heat stroke (DoH 2001). Although, given the experience in summer 2003, this seems likely to be a considerable underestimate of deaths from future higher temperatures and heat waves. These examples give an illustration of the some of the negative effects expected as a result of climate change.

However, the individual effects of climate change on the UK will not all be negative. For example, the increased temperatures are likely to reduce the number of excess winter deaths, which currently stand at between 20,000 and 50,000 per year (DTI 2001). In many sectors of the economy, it is not yet possible to know whether climate changes will lead to positive or negative effects – there is likely to be an element of both. For example in the agricultural sector, rising temperatures and longer growing seasons will give the opportunity to diversify and grow a greater range of crops, while changing rainfall patterns might require irrigation or water storage facilities to ensure summer water supplies. A changing climate could see new pests and diseases affecting crops and livestock and, as public taste responds to a changed climate, there may be shifting demands for existing farm produce (UKCIP 2004). While many of the consequences for the UK ecology, society and economy, under different climate change scenarios, are not yet understood, it is clear that the UK will not be immune from the world-wide political and economic disruptions which could be caused by serious climate change.

Since the 2001 IPCC reports, research news about climate change and its expected effects has, if anything, become more alarming. Two different studies from the UK Hadley Centre have suggested that increased carbon dioxide concentrations in the atmosphere may lead to higher temperature rises than those reported in IPCC's work (Clarke 2003, Murphy et al. 2004). The work of Murphy et al indicates that a doubling of carbon dioxide in the atmosphere would lead to range of temperature rises of 2.4 - 5.4°C, almost one degree Celcius higher than the 1.5 – 4.5 °C range reported by IPPC (2001a). There has also been alarming research about the prospects for mass extinction brought about by climate change. Researchers at Bristol University have shown that six degrees of global warming was enough to wipe out up to 95% of the species which were alive on earth 250 million years ago (Press Association 2003). Other researchers suggest that climate change over the next 50 years is expected to drive a quarter of land animals and plants into extinction, in a medium emissions scenario (Thomas et al. 2004). The consequences of greatly increased climate change could hardly be more serious.

1.2.3 The global and UK response

The world's governments have responded to the threat of climate change. In 1992, the United Nations Framework Convention on Climate Change was created. Its objective is for the world to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations 1992). However, the Convention did not define what level of carbon dioxide concentrations in the atmosphere would be dangerous or propose a date by which concentrations should be stabilised.

In order to put the objective of the Convention into action, the Kyoto Protocol was created (United Nations 1997). It was designed to be the first legally binding treaty aimed at cutting emissions of the main greenhouse gases. More than 150 nations signed it in 1997. Under its terms, industrialised nations (known as 'Annex 1' countries) committed themselves to a range of targets to reduce emissions between 1990, the base year, and the average emissions of the five years 2008-2012 (usually described as the 2010 target). The Member States of the EU jointly agreed to undertake an 8% reduction of six key greenhouse gases by 2010. The intention is to achieve this by a mixture of reductions for some nations and a cap on increases for others. The UK target is a reduction of 12.5% under the EU burden sharing arrangements. At present, non-industrialised countries do not have reduction targets. The net effect of Kyoto, if the targets are met by all the Annex 1 countries, will be to reduce industrialised countries' emissions by 5%. The Protocol's scientific advisers, the IPCC, say this will delay the effects of climate change by, at most, ten years.

The importance of the Kyoto Protocol, given that it aims to achieve only a minor reduction of greenhouse gases from Annex 1 countries, is both as a symbol of determination to limit climate change and as the first step in a series of future international treaties. However, the omens are not good. Firstly, the world's biggest carbon emitter, the USA, responsible for 23% of the global total in 2000 (Marland, Boden, & Andres 2003), has said it will not ratify the Protocol nor meet its previously agreed emissions reduction target. This was a major blow to the process and has undermined the authority and effectiveness of the Protocol. Nevertheless, it can go ahead without the USA, and in November 2004 Russia finally ratified the Protocol. It will therefore become legally binding on 16 February 2005 (Hogan 2004). Secondly, many of the countries which have agreed to Kyoto are not on course to achieving their targets. In the EU, the latest assessment is that ten of the fifteen (pre-2004) Member States are likely to miss them by a wide margin (Gugele, Huttunen, & Ritter 2003). Even those countries which were allowed significant increases in emissions under the EU burden-sharing arrangements, including Portugal, Spain and the Republic of Ireland are failing in their commitments. At present, it seems unlikely that the Kyoto Protocol will achieve its aims let alone lead the way to future treaties.

In contrast to most of its European partners, the UK is on target to meet its Kyoto target (Gugele, Huttunen, & Ritter 2003). However, as discussed in Chapter 2, most of the savings will come about because of fortuitous changes in the fuels used for electricity generation rather than because the UK is firmly on path to a lower carbon economy. The UK has also set itself relatively ambitious targets in addition to its obligations under the Kyoto Protocol. On the basis of a feasibility analysis carried out by the Royal Commission on Environmental Pollution (RCEP 2000), the government has committed itself to reduce carbon dioxide emissions by 20% by 2010 from their level in 1990. It has also declared that it is aiming for a 60% reduction by 2050, achievable in the view of the IPCC using existing technology. This target represents an important advance on Kyoto and in setting this target the UK government has shown admirable global leadership. Other European countries have now also adopted long term reduction targets. For example, the French government has set a target of emissions in 2050 of 0.5 tC per capita, a reduction of over 70% from current levels (French Interministerial Task Force on Climate Change 2004). These UK and EU targets and the likelihood of reaching them, and the policies introduced, are discussed further in Chapter 2.

Although the UK has adopted ambitious long-term and shorter-term carbon reduction goals, at the same time, decisions which can only lead to increases in carbon dioxide emissions, such as expanding airport capacity to facilitate an increase in air travel, are still being taken (DfT 2003b). The government belief seems to be that carbon dioxide emissions can be tackled primarily through technology changes (Blair 2003), and that more fundamental questions about lifestyles and 'sustainable' economic growth do not have to be addressed. This thesis will question these assumptions.

In summary, there has been a global response to climate change which recognises the seriousness of the problems and many developed countries have pledged to act to reduce greenhouse gas emissions. However, as Chapter 2 will demonstrate in detail, there have been few bold actions to match the brave words used by politicians when talking about climate change. At present, despite the pledges, the world is heading on the path towards six degrees Celsius or more of global warming within the next one hundred years, with all the consequences this would entail.

1.3 Scope and aims

This thesis concerns carbon dioxide emissions from fossil fuels in the UK, because these are the most significant national source of greenhouse gases. The requirement to save 60% of carbon emissions by 2050 is taken as a starting point, as the minimum the UK must achieve from the domestic sector (and all other sectors) in order that the UK makes a fair contribution to global efforts to reduce carbon dioxide emissions.

The research questions are:

- Is a strategy of relying largely on improvements in energy efficiency likely to achieve the required savings in the UK domestic sector?
- If not, could personal carbon rations offer an alternative route to savings?

In order to answer these questions, this thesis will:

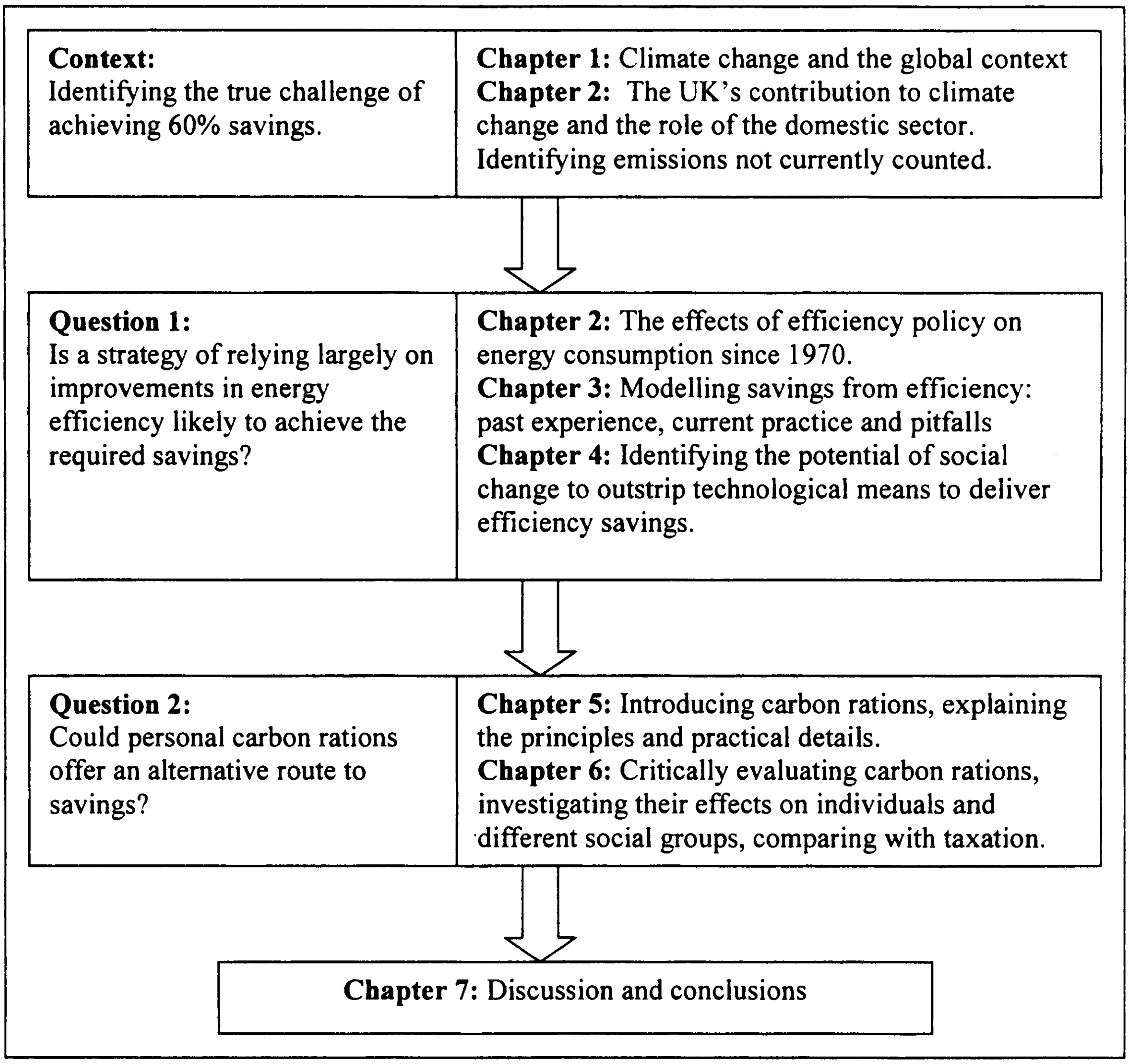
- Present data on the UK's energy use and carbon emissions, and show how including international aircraft emissions changes the picture.
- Review the role that demand-side energy efficiency has played in reducing energy use in the domestic sector since 1970.
- Evaluate whether current UK energy policy, based primarily on energy efficiency, is likely to be successful in delivering 60% carbon savings by 2050
- Explore, using a model, how plausible changes in behaviour or society could put at risk the potential carbon savings which previous studies have shown might be achieved through technology and energy efficiency improvements.
- Introduce and develop in more detail a new concept – personal carbon rationing – which would ensure a minimum of 60% reductions in carbon emissions can be achieved by 2050.
- Investigate the effects that carbon rationing would have on different sections of society, and compare its likely effects with those of an alternative policy option, energy taxation.
- Present original case study data showing the variation in current carbon emissions between individuals.
- Identify key further research necessary to advance the discussion about carbon rationing.

The focus of this thesis is household energy use and subsequent carbon emissions, and this sector is situated within the wider context of the whole UK economy. The boundaries of the research are extended beyond household energy use in two particular cases. First of all, in Chapter 2 research is carried out into the effect of including international air travel emissions in the UK's official emissions total. This was done in order to give a more accurate picture of the UK's progress in reducing carbon emissions. Secondly, in Chapter 5 where carbon rationing is introduced, personal transport energy use and its carbon emissions are included in the rationing scheme. This is because the policy mechanism of personal carbon rationing makes more sense when proposed for household and personal transport together than for household energy alone. However, the focus remains on household energy use and wider discussion of transport policy is not included within this thesis.

1.4 Thesis structure

The structure of the thesis is shown in overview in a flow diagram in Figure 1.1. Following this, each chapter is briefly summarised.

Figure 1.1: Overview of thesis structure



Chapter 2: Energy use and climate change

Chapter 2 sets out the key facts about energy use and carbon dioxide emissions, discusses recent trends in each of these. Two important sources of carbon emissions, which are not included the conventional UK total – international airline emissions and emissions from imported goods – are identified and quantified. The likelihood of meeting UK government and international carbon reduction targets is debated. Within the review of energy policy there is a particular focus on demand side measures, primarily energy efficiency. The role that energy policy and energy efficiency has played and could play in the future shaping of energy use and carbon dioxide emissions is debated. The fall in carbon dioxide emissions the UK has experienced over recent years is explained, and the implications for future emissions are outlined.

Chapter 3: Energy and carbon dioxide emissions modelling and future scenarios

This chapter explores and compares different approaches to modelling energy futures, describes a number of current energy projections and compares previous projections with what has subsequently happened. Analysis demonstrates that top-down economic models have consistently underestimated future energy use in the domestic sector. In addition, projections using bottom-up models have identified savings far in excess of those which have actually been delivered. Although current bottom-up models suggest 60% savings could be achieved by 2050, largely via energy efficiency improvements, there are good reasons to believe these potential savings have also been over-estimated. Several socio-economic scenarios, which can be used to look at energy futures, have also been reviewed. The scenario approach suggests only a change of values towards sustainability will result in significant savings. Finally the interaction of different modelling approaches is discussed, and lessons are drawn for future analysis.

Chapter 4: Modelling energy use and carbon dioxide emissions

Chapter 4 describes how an existing model of energy use in UK housing, developed by David Johnston (2003a), has been re-created and validated for use in this thesis. Johnston demonstrated that technological improvements to the housing stock could result in 60% carbon savings by 2050. However, detailed research shows how internal temperature, hot water demand and other variables could change so as to increase energy use and carbon emissions far beyond those envisaged by Johnston. Two new future scenarios, High Energy and Low Energy were created. A combination of the maximum improvements to energy efficiency with the High Energy scenario would lead to savings of just 17% of carbon emissions by 2050 compared with those in the base year of 1996. Conversely, in the Low Energy scenario, behavioural and social change could lead to greater carbon emissions savings by 2050 than those achievable through technology improvements. Finally, brief analysis of supply side options shows that the future carbon intensity of the domestic energy supply could increase, rather than fall as is commonly assumed.

Chapter 5: Introducing carbon rationing

Chapter 5 introduces the concept of personal carbon rations, defines their characteristics and considers the underlying principles. Then the existing literature on carbon rationing and similar policies is summarised to show how the definition in this thesis emerges from earlier work.

'Contraction and convergence', the most promising basis for a global agreement on carbon reductions, is described and the connection with UK carbon rationing is explained. Following this, practical aspects of introducing rationing are discussed. Firstly, Britain's most important example of mass rationing, food rationing during the second world war, is described and lessons are drawn from that experience for carbon rationing. Then policies and initiatives which could support people in living within their ration are described. These include greatly improved carbon information at the point of purchase of fuels, equipment and houses. Alterations to existing polices to support carbon rationing are suggested.

Chapter 6: Analysing carbon rationing

Chapter 6 takes a more critical look at carbon rationing and analyses it in further detail, both in terms of its own objectives and compared with other policy alternatives. New empirical data on personal carbon emissions are presented which show a variation of a factor of twelve between the emissions of thirty two individuals. The effects of carbon rationing on different groups in society, particularly those on lower incomes and single person households, are analysed. The characteristics which tend to lead to higher or lower emissions are summarised. Critiques of carbon rationing both in principle and in terms of practical concerns are addressed. The alternative policy of carbon taxation is discussed in some detail, and the advantages of carbon rationing in comparison are outlined.

Chapter 7: Summary, discussion and conclusions

The final chapter re-visits and summarises the key findings of the thesis and relates them back to the central question of the thesis: how can 60% carbon savings be achieved from the domestic sector by 2050? Linkages between different parts of the research and findings from different chapters are emphasised. There is reflection on the methodologies used to undertake the research. The original contribution to knowledge made by this thesis is clearly outlined and defended. Finally, areas for further research and unanswered questions are identified, and suggestions for changes to government data gathering and policies are made.

1.5 Methodological overview

This thesis combines a number of different approaches to investigate the central question of how 60% reduction in carbon emissions can be achieved from the domestic sector by 2050. The key methods used are:

- critical review of existing literature;
- numerical analysis using secondary data sources;
- bottom-up energy modelling;
- collection and analysis of original quantitative and qualitative data.

Table 1.1 summarises the methodologies which are used in each chapter of the thesis. Extensive use is made of existing secondary data because the thesis question concerns the whole UK domestic sector. It is beyond the scope of this research to collect nationally representative original data, and in any case much of the necessary quantitative data are available from government statistics. This thesis focuses chiefly on presenting original analysis using existing data, undertaking original modelling and presenting and developing a new policy idea, rather than generating new empirical data. However, original quantitative and qualitative data of an exploratory nature are also included in the thesis in Chapter 6.

Table 1.1: Summary of methodologies used in each thesis chapter

Chapter	Literature review	Analysis using secondary data	Energy modelling	Analysis using original data
Chapter 1	✓			
Chapter 2	✓	✓		
Chapter 3	✓	✓		
Chapter 4	✓	✓	✓	
Chapter 5	✓	✓		
Chapter 6	✓	✓	✓	✓

Because different methods of analysis are used in different chapters, and each chapter contains original work, the details of specific methods are contained in individual chapters, rather than having a separate chapter on methodology.

This PhD is in the field of energy policy – which is itself a multi-disciplinary area of enquiry. It includes elements of physics, climate science, geography, engineering, social sciences, philosophy, policy analysis and economics. This thesis focuses on numerical, technical and policy analysis. There is relatively little economic and social science analysis.

Research and policy in this area is currently changing. Significant changes to government policy and new research up to the end of November 2004 are included where possible. Changes after that date are not reflected in the text.

1.6 Conventions in this thesis

The key conventions in this thesis are:

- All energy figures relate to final (delivered) energy, unless primary energy is specified.

- TWh is used as the measure of UK and domestic energy use, this is so that the unit of measurement matches that used in key government statistics (e.g. DTI 2004a). MtC has been chosen as the measurement unit for carbon dioxide emissions for the same reason.
- Throughout the thesis, reference to the UK's total carbon emissions is on the IPCC measurement basis and does not include international air emissions, unless specifically stated.

Definitions are given in the text and in the glossary at the start of the thesis. Similarly, abbreviations are listed at the beginning of the document.

1.7 Note on joint research

During the time research was being undertaken for this thesis, the author also conducted parallel research for a book: 'How we can save the planet', Mayer Hillman with Tina Fawcett, published by Penguin Books in 2004. Some of the themes and areas of research are the same as those covered in this thesis. However, that work was for a general readership, and additional effort was required to bring the research up to doctoral level. Where Mayer Hillman's ideas or jointly developed ideas are used in this thesis they are acknowledged as Hillman & Fawcett (2004). However, if the research was undertaken or ideas developed solely or primarily by the author, they are included as the author's original work without further attribution.

Chapter 2: Energy use, energy policy and carbon dioxide emissions

2.1 Chapter overview

The aims of the chapter are to present key facts about energy use and carbon dioxide emissions, to analyse recent trends in each of these, and to describe current UK energy policy and consider whether it is likely to provide an adequate response to the challenge of climate change. The rise in energy use and the changing patterns of usage since 1970 are described. The main focus is on household energy use, but reference is also made to wider energy use issues where appropriate. Within the review of energy policy there is a particular focus on demand side measures, primarily energy efficiency. The role that energy policy and energy efficiency has played and could play in the future shaping of energy use and carbon dioxide emissions is debated. The fall in carbon dioxide emissions the UK has experienced over recent years is explained, and the implications for future emissions are outlined.

Findings include:

- The evidence over the past thirty years is that energy efficiency has not delivered energy savings for the domestic sector;
- New analysis shows that when the full global warming effect of international air travel is included, UK carbon dioxide emissions have not fallen since 1990.

Some of the subjects raised initially in this chapter are considered further in later chapters. Chapter 3 deals in detail with modelling of energy use. Chapter 4 includes more information on energy saving options, including efficiency measures, renewable energy provision and behavioural change.

2.2 Methodology

In this chapter, existing secondary data are used to present a background picture of energy use and subsequent carbon dioxide emissions in the UK. The data have been chosen to illustrate aspects of energy use most relevant to the thesis area of study. This information is also used to investigate the role energy efficiency has played in the domestic sector since 1970, and the extent to which it has delivered energy savings. In addition, existing statistics on UK carbon dioxide emissions and the emissions from air travel are combined to give a new insight into total carbon dioxide emissions from fossil fuel usage.

UK government policy on energy policy, domestic energy use and carbon emissions reduction is described. It is then reviewed critically, making use of the literature, to debate whether current emissions reductions targets are likely to be met. Potential contradictions in existing policy goals are identified.

2.3 Energy use overview

2.3.1 Introduction

In the last one hundred years energy consumption has increased vastly in comparison with previous times. For example, Smil (2000) estimates that in the year 2000 the world had at its disposal about 25 times more useful commercial energy than it did in 1900. McNeill (2000) suggests that more energy has probably been deployed since 1900 than in all of human history before 1900. Most of this energy has come from burning fossil fuels. Developed countries in particular depend very largely on these fuels for their energy needs. The UK is typical of this, deriving 90% of its total energy requirement from fossil fuels (DTI 2003a). It is hard to overstate the importance of burning fossil fuels for current patterns of economic, social and cultural life. It is this fact which makes drastic curtailment of fossil fuel use to prevent further climate change such a challenge.

This section outlines patterns of energy use in the UK, with a particular focus on the domestic sector.

2.3.2 Primary and final energy consumption

Energy consumption is usually measured in one of three different ways: primary energy, final energy (sometimes called delivered energy) and useful energy. The definitions here follow those used by the UK's Department of Trade and Industry (DTI 2004a).

Primary energy is a measure of the energy content of primary fuels plus primary electricity. Primary fuels are those obtained directly from natural sources, e.g. coal, oil and natural gas. Primary electricity is that obtained other than from fossil fuel sources, e.g. nuclear, hydro, wind and other non-thermal renewables[1]. Primary energy includes energy used or lost in the conversion of primary fuels to secondary fuels (for example in power stations), energy lost in the distribution of fuels (for example in transmission lines) and energy conversion losses by final users.

---

[1] For electricity not generated from fossil fuels or other combustible fuels, conventions are needed to define primary energy content. For electricity generated from hydro and wind, primary energy equals final energy. For nuclear energy, primary energy is defined as the heat in the steam at the nuclear plant, before it is transformed into electricity (with an average efficiency of 38.05% in 2003 (DTI 2004a)).

Final energy, also known as delivered energy, is the energy consumed by final users. It is therefore net of fuel industry own use and conversion, transmission and distribution losses, but includes conversion losses of final users. It is the energy use as metered at the doorstep of a building. This is the measure of energy which will be most commonly used in this thesis.

Useful energy is that energy available after deduction of the losses incurred when final users convert energy supplied into space or process heat, motive power, light or other energy services. DTI states that *"statistics on useful energy are not sufficiently reliable to be given... there is a lack of data on utilisation efficiencies and on the purposes for which fuels are used."* (2004a:21)

Because of the losses in each stage of transformation: primary energy > final energy > useful energy.

In the UK over the past thirty three years, both primary and final energy use have increased. At the same time, the proportion of different fuels used to supply national energy demand has changed considerably, as illustrated in Figure 2.1.

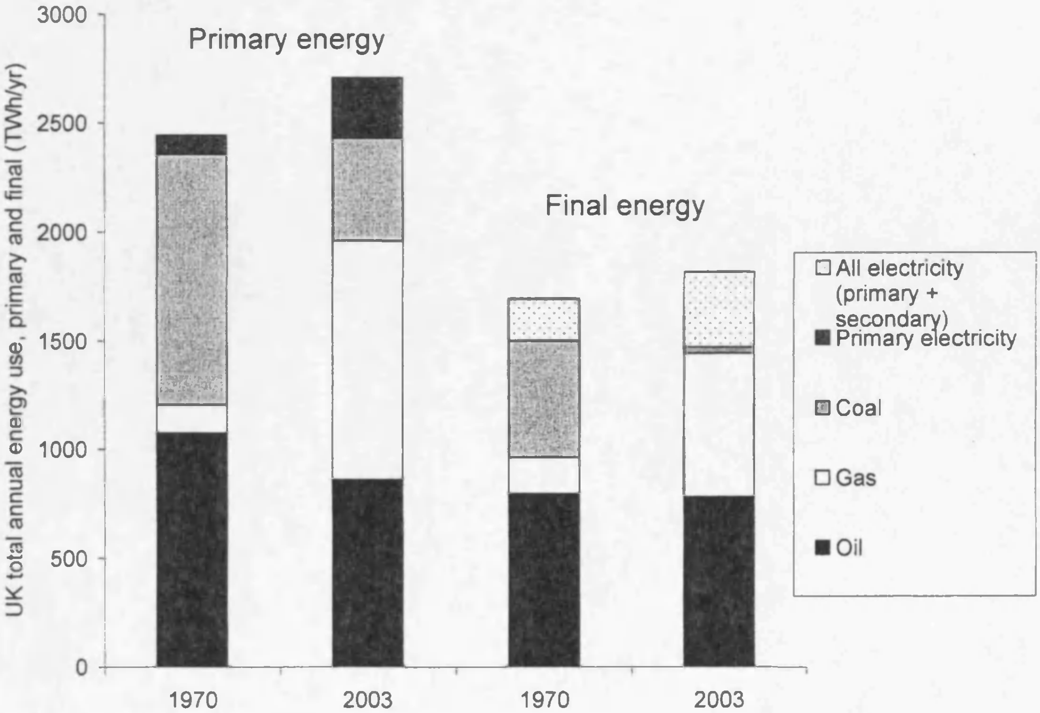


Figure 2.1: UK total annual primary and final energy use by fuel, 1970 and 2003

Source: DTI 2004a

Primary electricity includes that generated in nuclear stations, by natural flow hydro-electricity and wind energy. Secondary electricity is that generated by combustion of a fuel, usually coal, oil or gas.

Both primary and final energy use have increased between 1970 and 2003, primary energy by 10.8% and final energy by 8.2%. The ratio between primary and final energy for the UK was similar for both years, with final energy being 69.5% of primary in 1970 and 67.9% in 2003. Since the 'missing' energy is accounted for by conversion, transmission and distribution losses this shows that losses have increased over time, but this is not because production and delivery of final energy have become less efficient. As the graph shows, the percentage that electricity makes up of final energy has increased from 11.3% to 18.8% between 1970 and 2003. Generation, transmission and distribution losses involved in producing electricity account for most of the difference between primary and final energy, and so increasing electricity production increases losses. Because the efficiency with which electricity has been produced has increased, an expansion of electricity use has not greatly increased the losses between the primary and final energy stages.

Figure 2.1 also demonstrates that the usage pattern of primary energy fuels has changed markedly over the past thirty three years – with gas increasing hugely as a proportion of primary energy, oil decreasing somewhat, and coal decreasing considerably. There has also been an expansion in the supply of primary electricity, mostly due to an increasing contribution from nuclear power.

The proportion of final energy used by different sectors of the economy has also changed significantly since 1970 (Figure 2.2). Final energy use by industry has almost halved, while the transport and domestic sectors have experienced growth. Transport, which includes business as well as personal transport, is now the largest energy-using sector at 35% of the total. While this is the usual way in which the statistics are presented, it would also be possible to look at the amount of energy used in buildings (in the domestic, service and industrial sectors) other than for process energy. Total energy use in buildings is estimated to be about half of the UK total, considerably outweighing transport energy use (ODPM 2004).

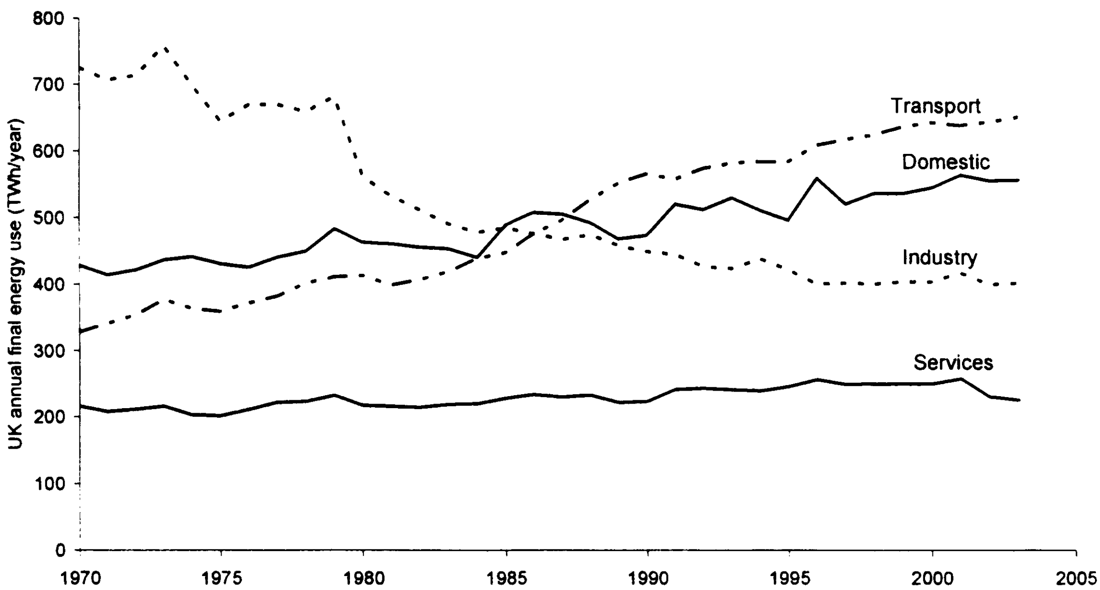


Figure 2.2: Annual final energy use in the UK by sector, 1970-2003

Source: DTI 2004a

2.3.3 Domestic energy use

Domestic energy use, also known as household energy use, is all the energy used within households in the UK. It represents a significant and growing proportion of UK final energy demand. In 2003, it amounted to 30.3% of the total final energy (DTI 2004a). It has been growing steadily over recent decades and continues to grow at over 1% per year (DTI 2003a). Understanding the reasons for increasing growth in energy use is key to knowing how this trend can be reversed. This section outlines how and why energy use in households has changed over recent decades.

Growth in energy use has been driven by the increasing numbers of households since 1970 (Table 2.1) as energy use per household has changed little over the period. In fact, final energy use per household has declined slightly from 23,200 kWh to 22,500 kWh in 2001 (in line with the higher temperature of 6.6°C in 2001 compared with 5.8°C in 1970) (Shorrock & Utley 2003). The annual energy consumption per household over the period 1970-2001 has varied relatively little, the average was 22,100 kWh, with the maximum and minimum values being within 7% of the average. Annual variations generally reflect changing external temperatures. Of household energy use in 2001, 62% was used for space heating, 23% for water heating and the remaining 15% for cooking, lights and appliances (Shorrock & Utley 2003). This pattern has changed relatively little since 1970, the biggest change being that the proportion of energy used by lights and appliances has almost doubled, whilst that used for cooking has fallen considerably.

It is perhaps surprising that energy use per household has not increased, given that its relative cost has decreased considerably since 1970. In real terms (i.e. adjusted for inflation) household fuels have become less expensive; the price of gas has fallen by 39% between 1970 and 2003, and electricity prices have fallen by 15%[2] (DTI 2004a). Over the same period incomes have grown considerably, so energy prices have fallen dramatically relative to incomes. Energy costs were just 2.9% of the average household budget in 2001/02 (ONS 2003a), which is less than the average spend on alcohol. This compares with an average of 6.3% in 1970 (Shorrock & Utley 2003). Despite this, in 2001 there were still an estimated three million UK households in fuel poverty, that is to say they would have to spend at least one tenth of their income to afford adequate energy services (DEFRA & DTI 2003). Nevertheless, in general the opportunities for using energy in the home have expanded and the cost of doing so has decreased over recent years.

The key reason that energy consumption has not increased per household, is that improvements in energy efficiency have enabled people to access greater energy services (e.g. warmer rooms) without having to increase their energy use. The factors influencing the change in household energy use since 1970 are summarised in Table 2.1. This shows in index form how various factors determining total GB household energy use have changed from 1970 to 2001. For space heating, energy consumption is determined both by how effectively the building retains heat, and by the efficiency of the heating system (and, of course, by the people). Both the efficiency of the building fabric and of heating systems has improved significantly since 1970. There has been a strong rise per household in the energy used in lights and appliances. Although energy use per household has changed little, due to increasing household numbers the total across the sector has risen. Thus there have been both downward and upward pressures on energy use, but the upward pressures have outweighed the impressive efficiency increases in both housing and the heating equipment.

[2] Recently there have been price rises. Domestic electricity prices rose by 3.2% in real terms in the year to Q2 2004. Domestic gas prices rose by 4.5% in real terms in the year to Q2 2004.(DTI 2004c)

Table 2.1: Final energy use and characteristics of GB housing stock, 1970 and 2001

	Actual values		Indices (1970 = 100)	
	1970	**2001**	**1970**	**2001**
Energy use in housing stock (TWh)	417	548	100	132
Number of households (million)	17.99	24.42	100	136
Average energy use per household (kWh)	23,200	22,500	100	97
Heat loss per average dwelling (W/°C)	376	259	100	69
Weighted average space heating efficiency (%)	49	70	100	143
Electricity consumption in lights and appliances per household (kWh)	1,680	2,840	100	170
Average energy use per individual (kWh)	8,000	9,780	100	122

Source: Based on Shorrock & Utley 2003

There are different responses to this data. One is to conclude that energy efficiency has not led to energy savings, because improved efficiency has allowed people to increase their use of energy services (Bell, Lowe, & Roberts 1996). An alternative interpretation is that demand for energy services would have risen in any case and that, without energy efficiency measures, energy consumption would have been much higher. This is the approach taken by Shorrock & Utley (2003), who suggest that their energy model shows that a saving of 46% has been delivered by energy efficiency, relative to what the level of consumption would have been in 2001 if no efficiency improvements had been made since 1970. However, the baseline used for this calculation is 'counterfactual'; it is an estimate of what would have happened if the interventions had not taken place. The type of assertions made in creating this baseline are impossible, in principle, to either verify or falsify (Jackson, Begg, & Parkinson 2001). Therefore, while the statement that energy efficiency has not resulted in sector wide savings over the past three decades can be made with certainty, the claim that without efficiency, energy consumption would have been much higher is open to debate.

2.4 UK carbon emissions

2.4.1 Introduction

The UK's carbon dioxide emissions are globally significant. UK emissions in 2003 were 153 MtC (DEFRA 2004a), which accounts for over 2% of the world total (Marland, Boden, & Andres 2003). Each UK citizen is currently responsible for about two and a half times the global average per capita emissions. Partly because the UK was the first country to industrialise its economy and use fossil fuels, its contribution to the total emissions since 1750 is much higher than the current contribution: overall, it has been responsible for 15% of global emissions (Marland, Boden, & Andres 2003).

Contrary to experience in most countries, UK carbon emissions have fallen in recent years (Section 2.4.2). However, the situation is not as positive as the data first seem to indicate. Section 2.4.3 investigates why UK emissions have fallen. Then two important classes of emissions which are not currently included in the UK total are investigated. Firstly, original analysis illustrates the difference that including international airline emissions makes to total UK carbon emissions (Section 2.4.4). Secondly, preliminary data on the emissions emitted abroad to supply the UK with goods is presented (Section 2.4.5).

2.4.2 UK carbon emissions data since 1970

Because carbon dioxide emissions are produced from tens of millions of fixed and mobile sources (e.g. homes, cars and factories), national emissions have to be calculated rather than measured. There are different methodologies for calculating carbon emissions; the two principal methods have been established by the Intergovernmental Panel on Climate Change (Houghton et al. 1996) and the United Nations Economic Commission for Europe (UNECE) (UNECE/EMEP 2001). The Intergovernmental Panel on Climate Change (IPCC) methodology includes land use change and all emissions from domestic aviation and shipping, but excludes international marine and aviation bunker fuels. UNECE excludes land use change and also international shipping, but includes aviation emissions below 1,000 metres to cover take-off and landing cycles (DETR 2001). For these reasons national totals reported under the two definitions are slightly different. Neither methodology includes emissions from international aviation – this is discussed further in section 2.4.4.

Figure 2.3 illustrates UK carbon dioxide emissions since 1970. Current official UK estimates of carbon dioxide emissions are calculated in line with IPCC reporting guidelines. However, data are only available on that basis from 1990 onwards. For earlier years, the only UK figures available are calculated on a UNECE basis. As Figure 2.3 illustrates, the difference between the two is relatively small, with IPCC emissions 3-4% higher than UNECE emissions. All carbon emissions figures from 1990 onwards are given on the IPCC basis unless otherwise stated. In 1970, carbon emissions were 185.3 MtC (UNECE method), in 1990 they were 164.8 MtC, and in 2003 emissions were 152.7 MtC — that is around a fifth lower than in 1970.

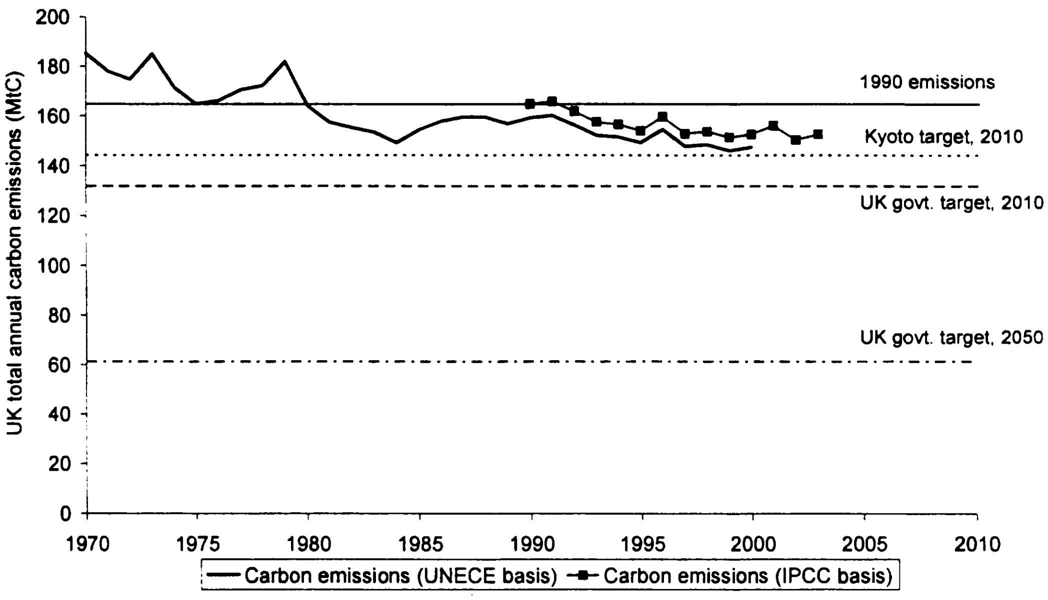


Figure 2.3: UK carbon dioxide emissions, 1970-2003

Sources: DEFRA 2004a, DEFRA 2003a

Also included in Figure 2.3 are the UK's three current carbon reduction targets, already mentioned in Chapter 1. To recap, these are:

- the Kyoto target of 12.5% reduction of the basket of six greenhouse gases from 1990 levels by 2010;
- the UK government's domestic target of a 20% reduction of carbon dioxide emissions from 1990 to 2010;
- the UK government's long term goal of a reduction of carbon dioxide emissions from current levels by 60% by 2050.

The prospects of achieving these targets are discussed in section 2.5.

2.4.3 Interpreting the UK's falling carbon dioxide emissions since 1970

Carbon emissions have fallen while energy use has risen because the UK has switched to less carbon-intensive fuels. Since 1970 total UK primary energy use has switched away from coal and oil, while the share of gas and primary electricity has increased (Figure 2.1). Primary electricity is almost carbon free, while gas is the fossil fuel of lowest carbon intensity (i.e. lowest carbon emissions per kWh) at around 60% that of coal, as the data in Table 2.2 show. Due to the changes in fuels used for electricity generation, the carbon intensity of electricity has fallen by 60% since 1970, and by 36% since 1990 and stood at 0.136 kgC/kWh in 2003.

Table 2.2: Carbon intensity of the UK's major energy sources

Energy source	**Carbon intensity, kgC/kWh**
Coal	0.082
Oil	0.068
Gas	0.052
Primary electricity	near to zero
All electricity*	1990 – 0.22 2002 – 0.136

Sources: DEFRA 2001a except for *, see Chapter 4, Section 4.9 for details of calculation

The switch towards lower carbon fuels has largely come about for reasons unrelated to climate change. It has been driven by factors including comparative fuel prices, increasing availability of natural gas, government policy, expansion of the role of nuclear power and changing fossil fuel power station technologies. Of the reduction in carbon dioxide emissions between 1990 and 1999, it has been estimated that just 40% was in response to climate change policy, with the remainder being due to special circumstances that cannot be repeated in future (Eichhammer et al. 2001). These special circumstances included the liberalisation and privatisation of the electricity and gas markets, reduced support for the UK coal industry and the introduction of the combined-cycle gas turbine (CCGT) technology - all of which made gas a more attractive fuel, particularly to electricity producers. Chapter 4 discusses the prospects for further reductions in the carbon intensity of the UK's energy mix.

2.4.4 Carbon emissions including all aircraft emissions

Presently, UK total carbon emission figures (IPCC basis) do not include the contribution of international aviation. In this section, existing data has been combined to provide an original estimate of UK total emissions including those from international air travel (Figure 2.4).

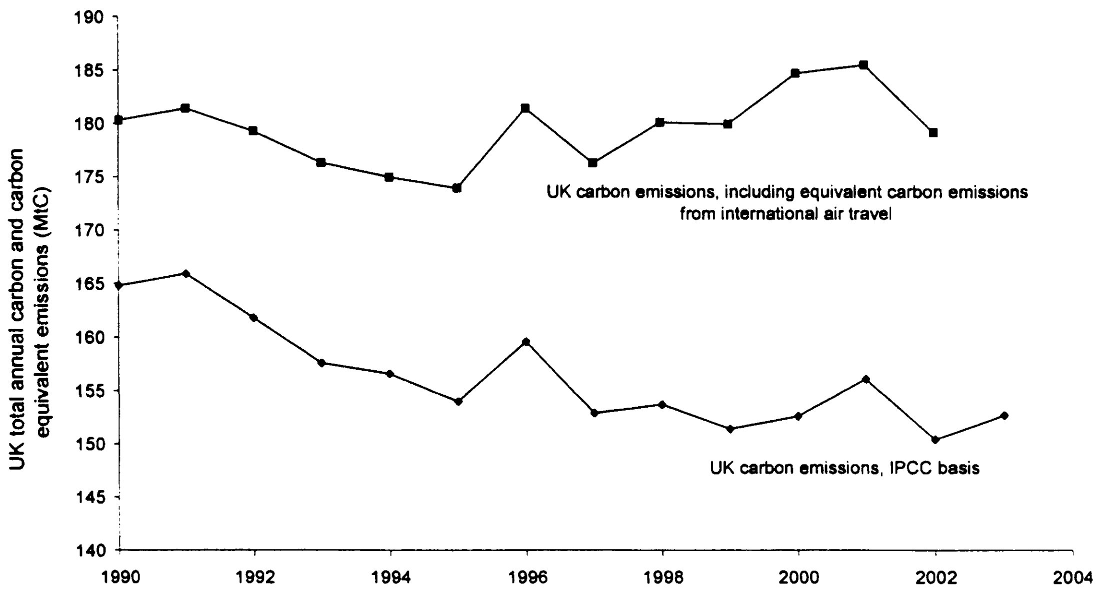


Figure 2.4 UK total carbon emissions and carbon equivalent emissions including international air travel, MtCe, 1990-2003

Sources: DEFRA 2004a, DEFRA 2003a, ONS & NETCEN 2004

Emissions from international aviation add significantly to the UK total. Air travel emissions from the UK were estimated at 8MtC in 2002 (DTI 2003b), which would add another 5% to national carbon emissions. Since then, further information about carbon dioxide emissions from the airline industry has been published for 1990-2002 (ONS & NETCEN 2004). This information shows that carbon dioxide emissions from air travel (domestic and international) were actually 10.1 MtC in 2002. Importantly, aircraft emissions add more powerfully to the greenhouse effect than the carbon dioxide component alone. The current best estimate is that they have three times the effect of carbon dioxide[3] (RCEP 2002). This makes their effective addition to carbon emissions 30.3 MtCe – that is million tonnes of carbon equivalent. However, the figure of 30.3 MtCe includes domestic and international air transport. Domestic air transport, which constitutes 5% of the global warming from UK national air travel (Bishop & Grayling 2003), is already included in IPCC emissions. Therefore, the figures for emissions from air transport have been multiplied by 0.95 and then added to the IPCC total. This takes total emissions including international air travel in 2002 to 179 MtCe, a 19% increase on IPCC figures (Figure 2.4).

[3] However, the question of how to compare properly the effects of aircraft emissions and those emitted at ground level is very complex and considerable further research is underway on this topic. The factor of three used here is provisional. The next authoritative statement about how to account for aircraft emissions is not expected from IPCC for a number of years (Jardine 2005).

There is little difference between emissions in 1990 and 2002, once international air travel is included. Carbon equivalent emissions from international air flights have risen by 13.3MtCe between 1990 and 2002 – just less than the 14.4MtC drop in IPCC emissions from 1990 to 2002 for the remainder of the economy. Not only are the emissions from international air travel already very significant, they are expected to grow rapidly into the future. On current forecasts, including overseas visitors, as many as 500 million passengers will use UK airports by 2030, nearly three times the present number of 180 million (DfT 2003a). The important role of international air travel makes it vital that these emissions are included in national and international greenhouse gas reduction targets.

The exclusion of international aircraft emissions from current targets is recognised as problematic by some commentators. For example, there have been calls for international aircraft emissions to and from developed countries to be included in UNFCCC national greenhouse gas targets by 2010 (Bishop & Grayling 2003). The Sustainable Development Commission has called for DfT and Defra to clarify the basis on which greenhouse gas projections are being made to ensure that full account is being taken of the radiative forcing of aviation (SDC 2004a). However, according to press reports, the UK government is keen to draw as little attention as possible to aircraft emissions to the extent of excluding them from official reports (Brown 2004b, Brown 2004a).

Throughout the remaining thesis, reference to the UK's total carbon emissions is on the IPCC measurement basis and does not include international air emissions, unless specifically stated.

2.4.5 Carbon emissions emitted abroad 'on behalf of' the UK

Current national emissions figures could be underestimating the UK's true global warming impact, if this country 'exports' some of its carbon emissions by importing more energy-intensive goods than it exports. That is, if other countries use energy and emit carbon on our behalf. There is economic evidence that the UK is likely to be an emissions exporter because far more goods are imported than exported. The UK is now considered a 'post-industrial' society and as Figure 2.2 shows, energy use in the industrial sector has fallen considerably since 1970, while that used in the service sector has risen. The UK has long imported more goods than it exports; the last surplus on trade in goods was in 1982 (National Statistics 2004b). In fact, the balance of trade in goods has shown a deficit in all but six years since 1900, with the value of imports exceeding that of exports. Other researchers who have raised the question of the UK's responsibility for emissions generated abroad (e.g Anderson, Shackley, & Watson 2003, Francis 2004) agree that the preliminary evidence points to the conclusion that the UK is 'exporting' emissions, but suggest much more detailed research is still required.

A recent press release from WWF accompanying their Living Planet report stated that the UK is responsible for almost 30% higher carbon dioxide emissions than the IPPC-based figures released by the government (WWF 2004a, WWF 2004b). The WWF emissions figure includes the carbon emissions embodied in imported food, goods and raw materials and excludes those from exports. WWF also include carbon emissions from international aviation (but do not adjust them to get the full carbon equivalent figures). Using this 30% figure, and subtracting the 6% that the carbon emissions from international air travel add to the UK total (Section 2.4.4), the conclusion is that imports add 24% to the UK carbon emissions total. This figure can only be regarded as indicative, as full details of WWF calculations are not included in their report and so their methodology cannot be critically examined (WWF 2004b). However, it does support the suggestion that significant additional carbon dioxide emissions are being emitted elsewhere in the world on behalf of the UK. Considerably more detailed research is still required to identify the true emissions being created abroad to meet UK demand for goods.

2.4.6 Discussion

The analysis in the three preceding sections has shown that:

1. while the UK's total carbon emissions have fallen since 1990, much of the reduction was fortuitous rather than as a result of fundamental shifts to a low carbon economy;
2. when international air travel emissions are included, UK emissions in 2002 were 19% higher than those reported on an IPCC basis;
3. initial evidence indicates the UK is likely to be responsible for significant additional carbon emissions generated overseas, due to our imports of energy intensive goods.

Together this evidence indicates that the challenge of achieving a 60% reduction by 2050 will be more difficult than currently acknowledged. Both the challenge of making savings and the true level of emissions for which the UK is responsible have been underestimated.

2.5 Energy and climate change policy overview

2.5.1 Introduction

Energy policy encompasses both supply and demand side issues. National supply side issues include the future of nuclear energy, support for the coal industry, renewable energy policy, oil exploration, and liberalisation and regulation of the privatised energy industries. Demand side issues include energy efficiency, household-level renewables and combined heat and power schemes. Some of the factors which determine patterns of energy use, such as international energy prices, are hard for national governments to influence and are beyond the traditional boundaries of energy policy.

In this thesis 'energy policy' is primarily used to mean demand-side energy policy. Firstly the overall goals of UK energy policy (demand and supply side) are described and discussed. This is followed by an outline description of current policy in the household sector. Then there is a discussion of whether current policy is likely to make sufficient savings to meet the UK's 2010 Kyoto and domestic goals for carbon emissions reduction.

2.5.2 Goals of UK energy policy

In 2003, the UK government published the Energy White Paper, the first major energy policy document for many years (DTI 2003b). This identified four goals for energy policy:

1. "To put ourselves on a path to cut the UK's carbon dioxide emissions – the main contributor to global warming – by some 60% by about 2050, as recommended by the RCEP, with real progress by 2020;
2. To maintain the reliability of energy supplies;
3. To promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity;
4. To ensure that every home is adequately and affordably heated."

The first goal is a clear demonstration of the concern of the government about climate change, and a promise to move towards a lower carbon economy. This commitment was widely welcomed by a wide range of organisations from Greenpeace to British Nuclear Fuels (ENDS 2003a). The second goal concerning reliability or 'security of supply' is a traditional concern of governments. Most householders are now dependent on centralised supplies of gas and electricity which cannot be stored at household level (this compares with 1970 when the most popular heating fuel, solid fuel, could be stored in some quantity by householders (Shorrock & Utley 2003)). If anything, reliability has become of greater importance over time; an increasingly centralised energy system makes reliability of supply more critical to people's well-being. The third goal makes explicit the government's view of the link between energy, and energy prices, and economic growth. The fourth goal puts elimination of fuel poverty at the centre of government energy policy.

These goals may conflict with each other. In fact, it has been recognised that trade-offs will have to be made (House of Commons Environmental Audit Committee 2003). The most likely conflict is between the first and third goals. All other things being equal, a competitive energy market leading to higher economic growth is likely to be in conflict with the goal of reducing carbon dioxide emissions. The issue of whether 'sustainable economic growth' which protects the climate is possible is fundamental to responding to climate change. It is a question which is currently being addressed by the government's Sustainable Development Commission (SDC 2003), but was not addressed in the Energy White Paper itself.

2.5.3 Definition of energy efficiency

The efficiency of any energy conversion system is defined as the useful energy output divided by the total energy input (Ramage 1997). This definition is relatively straightforward to apply in the case of systems providing easily measured outputs such as space heating or electrical power. So, for example, efficiency figures for gas boilers are available and they communicate how much of the chemical energy in the gas is converted into heat energy to be delivered to radiators, and conversely how much is 'lost' as heat in the wrong place (in the exhaust gases from the boiler) under test conditions. Similarly, the energy efficiency of a fossil fuel power station is the percentage of chemical energy in the primary fuel which is turned into electrical energy. However, defining and measuring useful energy outputs can be more difficult for equipment and systems supplying more complex services.

The complexity of defining 'useful energy' in some cases is illustrated with two examples. In order to develop a test for the efficiency of water heaters, the issue of 'tapping patterns', i.e. how much hot water was demanded and how many times hot water was demanded throughout the day, was critical (NOVEM 2001). Depending on the tapping patterns used for the test, the measured efficiency of different hot water heaters varies. So in real life, the useful energy delivered by hot water systems depends how the householder uses their system, and is not just a function of the equipment. Difficulties in defining what constitutes an energy service also make measuring efficiency problematic. For example, should the efficiency of a frost-free freezer be measured against the same criteria as a conventional freezer? This question goes beyond measuring the efficiency of a refrigeration system, because for frost-free freezers the service being offered includes not having to de-frost a freezer manually. Thus, although energy efficiency is a simple concept, creating usable definitions for household equipment, and relating efficiency under test conditions to real life efficiency, can be surprisingly complex.

2.5.4 Energy efficiency in different policy contexts

Energy efficiency has been used as a means to meet three different policy goals over recent decades: energy conservation, economic efficiency and carbon emissions reduction. The oil price energy crises in the 1970s prompted governmental and public interest in better management of energy. There was considerable concern that fossil fuels were in short supply and that the world was running out of them. Energy conservation became an explicit focus of government attention, with public education campaigns such as 'Save it!'(Jones 1995). At this time energy efficiency was seen a means to achieve energy conservation. During the 1980s, oil prices fell and the focus on energy conservation diminished. There was considerable attention on justifying public investment in energy efficiency from an economic standpoint. Economic arguments were developed to demonstrate that the market would deliver less than optimum levels of efficiency due to market imperfections such as lack of information. During this period, energy efficiency was partly promoted as a means of improving economic efficiency. In the mid to late 1990s, climate change concerns became an increasingly important factor in energy policy. Energy efficiency was once again seen as an important policy, this time as a tool for achieving carbon emission reductions and also for helping to reduce fuel poverty (DETR 2000a). This re-invention of the role of energy efficiency to fit the energy policy goals of the time could be argued to put too much reliance on efficiency policy to deliver targets other than the more efficient use of energy.

2.5.5 Meeting 2010 carbon reduction targets

The UK government expects to meet its Kyoto target and is optimistic that it will reach the domestic 20% reduction in carbon dioxide by 2010 (Beckett 2003). There is general agreement that the UK is likely to meet its Kyoto target (e.g. IEA 2002b, EEA 2003). However, there is a substantial body of opinion which doubts the 20% target can be met given the current policy measures. The Sustainable Development Commission (the government's independent advisory body on sustainable development) published a detailed report in 2003 (SDC 2004b) on the likely effect of the government's Climate Change Programme. They suggest that emissions of CO_2 will fall by at most only 12.6% by 2010, and perhaps substantially less. A recent report from the Institute of Public Policy Research also concludes that, unless there is radical policy change, the government will not meet its 2010 target (Mitchell & Woodman 2004). Other organisations have questioned the likely effects of particular parts of the programme. Research carried out by the ENDS Journal suggests that many of the commitments made under the industrial voluntary emissions trading scheme will not result in additional savings (ENDS 2003b). Similarly, the Association for the Conservation of Energy believes that the savings from the Climate Change Levy have been overstated (Waller 2003). Perhaps surprisingly, provisional forecasts by the Department of Trade and Industry also suggest that the government is off course for its 2010 CO_2 reduction target (DTI 2004e). Emissions in 2010 are expected to be just 15% lower than in 1990, even taking into account the expected effects of climate change policies (more details about this forecast are included in Chapter 3). Remember that this discussion excludes the effect of international aviation.

2.5.6 Longer term carbon reduction goals

The UK's long term goal for carbon reduction is based on work by the Royal Commission on Environmental Pollution (RCEP), which recommended that the UK should adopt a target of 60% reduction of carbon dioxide emissions from 1997 levels by 2050 (RCEP 2000). This target was based on 'contraction and convergence'[4] principles with the aim of ensuring that an upper limit of 550ppm carbon dioxide in the atmosphere is not exceeded globally (this is around twice the level of carbon dioxide there was in the atmosphere pre-Industrial Revolution). It was adopted as government policy in the 2003 Energy White Paper (DTI 2003b). However, the UK government has not adopted the principles of contraction and convergence as the basis for a future global agreement, and it is unclear how it intends to promote a global limit of 550ppm. This issue is discussed further in Chapter 5, Section 5.5.

This 2050 target is based on a particular judgement about the risks of increasing climate change and what level of risk should be accepted. RCEP judged a maximum atmospheric concentration of 550ppm would limit climate change to that which would be manageable. Several commentators suggest this is not sufficiently risk averse and that a lower limit of 450ppm would be a more responsible target (Athanasiou & Baer 2002, Hillman & Fawcett 2004, Meyer 2000). A 450ppm target would require greater than 60% savings by 2050 in the UK. While the focus in this thesis is on the 60% target, in future more stringent targets may be acknowledged as necessary, and the implications of this are discussed briefly in Chapter 5.

2.6 Energy policy for the domestic sector

2.6.1 Demand side measures

Following the publication of the Energy White Paper (DTI 2003b), a more detailed document, "Energy efficiency: the government's plan for action", has been produced (DEFRA 2004b). This explains how energy efficiency will contribute to the goals of UK energy policy and identifies the carbon savings it is expected to achieve in each sector. It builds on earlier work in the DETR's Climate Change Policy document (DETR 2000a). The government now expects domestic energy efficiency to deliver 4.2MtC carbon savings by 2010 (Table2.3). This is somewhat less than the 5 MtC suggested in the Energy White Paper (DTI 2003b).

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[4] Contraction and convergence (C&C) is a framework for global carbon reductions. It ensures that over time firstly global carbon emissions would contract and secondly there would be global convergence to equal per capita shares of this contraction (Meyer 2000). C&C is discussed in greater detail in Chapter 5.

Table 2.3: Measures and programmes to deliver carbon savings to 2010 in the domestic sector

Measure	Carbon savings (MtC)
Measures already in the UK Climate Change Programme	1.5
Energy Efficiency Commitment from 2005, Decent Homes	1.4
Warm Front	0.2
Community Energy	0.1
Building Regulations 2005	0.8
Other measures	0.2
Total domestic	**4.2**

Source: DEFRA 2004b

DEFRA (2004b) identifies key risks for delivery of Energy White Paper energy efficiency goals. The most significant high risk areas include poor enforcement, efficiencies being swamped by rising use of energy consuming products, and delays in reaching agreement on EU and international policies. Overall, DEFRA suggests that there is a 'medium' risk that energy efficiency measures will not deliver the required carbon savings.

The measures in Table 2.3 are continuations of existing policies, each of which is explained briefly below.

- **Measures already in the UK Climate Change Programme** are earlier incarnations of the Energy Efficiency Commitment, Warm Front and Community Energy programmes (see below for details) and Building Regulations 2002.
- The **Energy Efficiency Commitment** (EEC) is the current obligation on gas and electricity retailers to achieve energy savings. It is described by the government as "the principal policy mechanism driving increases in the efficiency of existing homes" (DEFRA 2004b). Savings are achieved most commonly by subsidising consumer purchase of efficient lights, appliances and loft and cavity wall insulation.
- **Decent Homes** is a government programme delivered through local authorities and social landlords to improve the efficiency (and other characteristics) of the social housing stock.
- **Warm Front** is a programme in England which improves efficiency and heating systems in homes of people on low income, with the overall aims of reducing fuel poverty and improving health.
- **Community Energy** is a programme encouraging the use of combined heat and power.
- The savings from **Building Regulations 2005** will come from higher standards for new boilers in existing homes in England and Wales.

There are other important policies which also influence energy use. The key influence on new housing is Part L of the national Building Regulations, which specifies the energy efficiency standard a property has to meet. The true influence of Part L does not show up in Table 2.3 because it relates primarily to new housing, the creation of which by definition increases energy use within the sector (because rates of new building much exceed the rate of demolition – as discussed further in Chapter 4). The scope of Part L has been increasing over recent years, in 2002 it set standards for the efficiency of replacement windows in existing buildings – moving beyond controlling just new housing for the first time (ODPM 2001). This move to increase control over existing buildings will continue in future regulations. The 2005 regulations aim to set higher standards (exceeding the current EU standard) for the minimum efficiency of new and replacement boilers in all houses (ODPM 2004). These regulations are still in the consultation phase, so final details are yet to be confirmed.

Other key policies include EU energy labels for lights, appliances and boilers, without which some UK policies would be unable to operate. There are also EU policies in place on either a mandatory or voluntary basis setting minimum efficiency standards for several types of appliance, including boilers, fridges and freezers, TVs and VCRs.

An important policy which comes into force in January 2006 is the EU Energy Performance of Buildings Directive, which will require the supply of energy performance certificates when *all* buildings are constructed, sold or rented out (DEFRA 2004b). Other provisions of the Buildings Directive are already largely covered by the UK's Building Regulations. The government has the option of delaying introduction of the Directive's provisions until 2009, but it is not yet clear whether they will do so.

2.6.2 Household level renewable energy

Most renewable energy policy is focused on increasing the supply of renewable electricity into the public distribution system. The overall goal is that 10% of electricity should be from renewable sources by 2010. The prospects of reaching this goal are discussed in Chapter 4. However, there are also some measures to encourage householders to install domestic renewable energy systems. There are grants available to install solar water heating and other small-scale renewables through the £10 million Clear Skies programme set up in 2003, to run for four years (DEFRA 2004b). However, this enabled fewer than 1,600 grants to individual households in the first year of operation – demonstrating the small scale of the programme.

2.6.3 Discussion

Improving energy efficiency has been, and remains, by far the most important government policy for the domestic sector, with renewables in the domestic sector only having a small role.

Within energy efficiency policy, emphasis is on technology improvement through regulation or voluntary agreements (e.g. Building regulations, EU appliance efficiency standards) and also on subsidies for efficiency improvements (e.g. EEC, Warm Front) which are paid for either by energy consumers or general taxpayers. There is no significant use of economic instruments, and the government is currently committed to not raising taxes on domestic energy (HM Treasury 2002).

The recent 'Energy efficiency' document (DEFRA 2004b) did not include any novel policies, all are continuations of existing schemes. Increasing demand for energy services was identified as a high risk factor threatening the planned savings, but no specific policies were introduced to address it. Historically this has also been the case, with little policy on reducing demand beyond occasional information campaigns such as the 'are you doing your bit?' campaign, and elements of the Energy Saving Trust's information campaigns. The other particularly serious omission is the lack of a framework for increasing the efficiency of existing homes. Instead there is a patchwork of policies affecting purchase and installation of efficient technologies and additional insulation. While building regulations provide a framework for regulating the efficiency of new homes[5], there is no comprehensive equivalent for existing homes. The new EU Buildings Directive will be a step towards remedying this situation by introducing labelling, but it may not come into force until 2009. In any case, as it only applies at the point of sale or renting, it will take decades to affect the whole of the existing UK housing stock. The assessment that current policies are only at 'medium' risk of not delivering the government's target savings by 2010 seems remarkably optimistic, given that very similar policies over recent years have not prevented energy use in the domestic sector from rising. The risks that rising consumption poses to projected savings from efficiency improvements are analysed in detail in Chapter 4.

2.7 Summary and conclusions

Energy use

Energy consumption in the UK economy and in the domestic sector is rising. Despite many changes in technology and ownership of household equipment since 1970, patterns of energy use by end use have changed relatively little and the average energy consumption per household has remained about the same (although without the improvements in efficiency that were achieved over the period, it would almost certainly have risen considerably). Per person, energy use has increased. For the economy as a whole, over the past thirty years there has been a shift towards lower carbon energy sources, especially natural gas and nuclear power, and away from

[5] At least in theory, although there is some concern about how well the standards are implemented and enforced in reality (Lowe & Bell 1998)

the most carbon-intensive fuel, coal. Chapter 4 will consider how much more scope there is for adopting lower carbon fuels in the UK.

Carbon dioxide emissions

The UK's record on carbon dioxide emission reductions initially appears very impressive, emissions have fallen considerably since 1970 and it is likely to be one of the very few nations to meet its Kyoto reduction targets. This is in spite of rising energy demand. Further investigation indicates the situation is not as positive as it seems. Firstly, much of the reduction in carbon emissions was largely due to changes in fuel sources, for reasons unrelated to climate change policy. Secondly, when international airline emissions are taken into account, UK emissions have not fallen since 1990. The prospects for future savings based on current policies are uncertain, particularly when the carbon equivalent emissions from international air travel are included. The remainder of the thesis works towards identifying a new policy which could deliver secure carbon savings in the domestic sector.

Government policy

From the preceding discussion it is possible to draw the following provisional conclusions regarding current government policy on energy and climate change:

- The UK needs a negotiating strategy for achieving a global carbon reduction framework beyond Kyoto, without this its 60% target for 2050 will lose its meaning as a contribution to preventing maximum atmospheric concentrations of CO_2 exceeding 550ppm.
- The UK government is highly unlikely to meet its own goal of 20% carbon emissions reduction by 2010, and could miss it by a large margin.
- As the fastest growing source of carbon dioxide, international air travel emissions should be included in UK government figures and environmental indicators as a matter of urgency, without waiting for an international agreement on accounting for international air movements.
- There are several inherent tensions and contradictions in the goals of the government's energy policy, including the question of whether economic growth is consistent with reducing carbon emissions.
- Energy efficiency has been used to try and deliver goals other than the more efficient use of energy over recent decades. This has not been successful in the domestic sector. For example, energy efficiency on its own has not been sufficient to enable savings to be made in comparison with previous years (i.e. energy conservation). This is not to deny that improved efficiency has helped reduce energy use compared with what would have been expected otherwise.
- There has been, and remains, very little policy oriented towards energy saving.

Energy efficiency has been the most important policy tool in the domestic sector. Its uptake has been encouraged primarily by regulation, information and subsidies. However, although the use of energy has become much more efficient in households, this has not resulted in energy saving at a household level due to a contemporaneous increase in demand for energy services. Given that UK policy for the domestic sector is almost wholly reliant on efficiency to make energy and carbon emissions savings, this is of concern and is considered further in following chapters. Chapter 3 considers modelling methodologies, and investigates past modelling of potential savings from energy efficiency. Chapter 4 uses bottom-up energy modelling to explore the possibility of increased energy demand outstripping savings from increased efficiency.

Chapter 3: Energy and carbon dioxide emissions modelling and future scenarios

3.1 Chapter overview

This chapter explores and compares different approaches to modelling energy futures, describes a number of current energy projections and compares previous projections with what has subsequently happened. Top-down, bottom-up and scenario modelling are all described, with future projections from prominent studies being presented and critically evaluated. The Department of Trade and Industry's top-down energy projections from the late 1980s onwards are compared with subsequent energy use data – and the discrepancies between the projections and reality are discussed. Projections from two bottom-up studies from earlier decades are presented, compared with actual energy use and lessons are drawn from these for present day modelling studies. Following this, the different modelling methods are compared and the interactions between different approaches are identified. Bottom-up modelling combined with insights from scenario methods is best suited for use in this thesis. However, the weaknesses of bottom-up modelling are identified and discussed.

3.2 Methodology

This chapter uses literature review to identify the main approaches for looking at the future of energy use in the UK and in the domestic sector in particular. General approaches of looking to the future are presented briefly and the key approaches for looking at household energy use are located within this overview. The two key approaches for the domestic sector are identified as top-down and bottom-up. Key examples of each type of model are identified and their results are summarised and presented, and they are compared with each other. This research forms the background against which the decision is taken about which type of modelling is most suitable in theory to help answer the thesis questions.

Projections from top-down and bottom-up studies made some years ago are compared with subsequent actual energy use data. Comparing past projections with what has actually happened is a surprisingly rare activity. In this chapter it gives new insights into both the performance of projections, the reasons why they might not resemble subsequent real-life energy use, and what the consequences of these differences might be. Particular attention is focussed on analysing the reasons why two particular examples of bottom-up modelling projected far lower energy consumption than has actually occurred. The results of this analysis are broadened to a general discussion about the weaknesses of bottom-up models and assessments of the likely savings from energy efficiency both in principle and practice. Data on the energy consequences of installing efficiency measures are compared with the savings modelled prior to their adoption.

3.3 Approaches to thinking about the future

Domestic energy modelling is largely concerned with making projections about the future and exploring alternatives, rather than understanding past and present aggregate energy consumption. Current patterns of household energy use and consequent emissions of carbon dioxide in the UK are reasonably well understood. Much of the understanding of energy consumption has emerged from modelling-based research, as opposed to from end-use measurement within households. There have been few monitoring studies because of their relative expense and difficulty compared to modelling (Oreszczyn & Lowe 2004).

Exploring the future of energy use is fraught with difficulties. As the physicist Niels Bohr supposedly said: *"it is difficult to make predictions, especially about the future"*. For decades, governments, industry and researchers have been producing energy projections which are often proved badly wrong only a few years later. Important variables in the world of energy change unexpectedly and relatively quickly: energy prices, fuel preferences, technologies. In addition to the difficulties of allowing for the unexpected, the factors determining energy demand and their relationships are imperfectly understood, and always in flux. Despite the difficulties, many reasons for looking into the future remain, and so the activity continues. Indeed concerns about climate change have increased interest in looking into the future because of the long-term nature of the threat.

A wide range of organisations publish their views about the future of energy use. They include government departments (DTI 2000), university and other researchers (Shorrock & Dunster 1997, ICCEPT 2002), business (Shell International 2001), non-governmental organisations (McLaren, Bullock, & Yousuf 2002) and 'futurists' (Margolis 2001). The range of researchers and modellers bring to bear different techniques, degrees of expertise and academic credibility, and varying aims and objectives in thinking about the future of energy use. It is important to recognise that the aims of the thinking about the future can vary, as can the techniques used.

As the Performance and Innovation Unit (PIU), a government research unit, note, futures work considers possible, probable and preferable futures, and a particular study can be about any or all of these three (PIU 2001a). Depending on its aims, research about the future can:

- describe likely developments
- plan / prepare for future developments
- explore alternative possibilities

- design a different future and propose means of achieving it.

The projections undertaken by the Department of Trade and Industry for planning purposes (e.g. DTI 2000) are investigations of likely developments and probable futures. By contrast, scenario work tends to look at a wide range of possible futures in an imaginative and coherent way. Often the most likely future is identified from amongst the imagined possibilities. Much of the work by researchers and campaign groups concentrates on identifying preferable futures and showing the potential for change (e.g. Johnston 2003a, DECADE 1997, Fawcett, Lane, & Boardman 2000, McLaren, Bullock, & Yousuf 2002). Chapman's statement is characteristic of this group: "*Rather than trying to predict the future I am trying to do exactly the opposite – to show the degree to which the future is under our control.*" (Chapman 1975:121)

There is common agreement that energy futures studies should aim to produce projections, which are an account of what *might* happen, and not predictions, which are about what *will* happen (DECADE 1997). As a UK government report stated "*Predictions are usually wrong, often misleading and sometimes positively counterproductive*" (Cabinet Office Strategy Unit 2000). The distinction between predictions and projections, and the ways in which they are used, is not always clear cut in practice, however.

PIU (2001a) have identified the six methodologies most commonly used by professional futurists. The two most common methods used in energy futures studies are quantitative trend analysis, often used to produce models of energy use, and scenario methods. These are described in detail below. The other techniques are: qualitative trend analysis; Delphi survey (gathering information or beliefs anonymously from a panel of experts); wild cards (identifying events which although they have a low probability of occurring would have a big impact if they did), and; future workshops (a participative process, usually identifying preferred futures). Individual techniques tend to be suited to different questions, levels of detail and time scales.

Quantitative trend analysis uses numerical analysis of past trends and relationships to act as a guide to the future. This type of analysis is based on assumptions about what the important forces and factors underlying present and future energy use are. There are different approaches to studying what drives energy consumption, and these have resulted in two different types of modelling based on quantitative analysis: 'top-down' and 'bottom-up'. Many studies using detailed quantitative modelling do not go beyond 20 years into the future because the uncertainties in projections become greater over time and the likelihood of significant unforeseen changes increases. Scenario methods also permit a variety of approaches and depths of analysis. For longer time periods, scenario approaches can be more useful. Commonly a combination of methods will be used, for example, scenario exercises are often based on a degree of quantitative modelling.

3.4 Top-down projections of energy use

3.4.1 What they are

'Top-down' is the description of energy models which take as their starting point the relationship between the economy and energy use. These models use econometric equations (and past data) to model the relationship between the two, at national or sector levels. By projecting forward economic factors, such as energy prices and economic growth, they provide projections of future energy consumption. They rely on aggregate economic behaviour to predict future changes in energy use and carbon dioxide emissions.

3.4.2 Current projections

The key source of top-down forecasts in the UK is the Department of Trade and Industry Energy Papers. The government has been issuing energy projections for the UK at varying intervals since 1977. The most recent finalised set of projections, *Energy projections for the UK; Energy Paper 68* (DTI, 2000), presents the Government's projections of future UK energy demand and related emissions of carbon and sulphur dioxides to 2020. These projections underpinned the Climate Change Programme launched by the DETR in November 2000 (DETR 2000a). The projections are based on an analysis of historical trends in energy use and its relationship to factors such as economic growth and fuel prices. They also reflect the effect of existing government policies on energy, but do not include the effects of the Climate Change Programme policies. Two different fuel price scenarios (low and high) are generated, and energy demand is then calculated for three variations on the rate of economic growth: low, central and high – resulting in six scenarios. These projections contribute to policy development and assessment of the UK's efforts to meet its national and international greenhouse gases targets.

The DTI projections suggest there will be a growth in energy use, but that up to 2010 carbon dioxide emission will decline. Primary energy demand is projected on central scenarios to grow at 0.7-0.8% per year to 2010; final energy demand is expected to grow at about 1% per year. Growth is expected to be strongest in the transport sector; the domestic and service sectors also show strong growth. However, the structural shift in the economy away from heavy industry is expected to continue, giving low growth in this sector. Despite growth in energy demand, carbon dioxide emissions are likely to fall up to 2010, due largely to the continuing switch to gas in the electricity supply industry, but after that to begin rising to 2020. In the central scenarios, CO_2 emissions are expected to still be just (1-3%) below 1990 levels by 2020, but are on an upward trend.

DTI has recently published provisional updates to these energy projections (DTI 2003c, DTI 2004e). These projections take account of the government's policies to reduce carbon dioxide emissions, unlike those in Energy Paper 68. The projection for energy use in the domestic sector is lower than that made for the CH scenario in Energy Paper 68, see Figure 3.1. Overall, carbon dioxide emissions for the whole economy are expected to be 142 MtC in 2010, a 15% reduction on 1990 levels (DTI 2004d). This projection includes the expected effects of the UK's climate change policies as well as the EU Emissions Trading Scheme.

Cambridge Econometrics also publishes forecasts for carbon dioxide emissions based on their integrated energy-environment-economy model of the UK (Cambridge Econometrics 2003). Full details of the modelling are only available to subscribers, however, summaries are made public. Projections are published every six months. According to the July 2003 projection, carbon dioxide emissions in 2010 will be 12.5% lower than in 1990. The projection six months earlier suggested higher emissions in 2010, at 8.5% lower than 1990. The difference in projections reflects different assumptions about emissions from the power generation sector and the impact of the EU Emissions Trading Scheme. This change in projections published just six months apart not only demonstrates the sensitivity to input assumptions common to all models, but also the vulnerability of emissions reductions targets to factors which may be beyond the influence of UK energy policy.

3.4.3 Lessons from previous top-down forecasts

Over time, DTI projections for energy use by the domestic sector have changed. This is not in itself surprising, what is perhaps surprising is how much the projections have changed over a relatively short time. Figure 3.1 shows projections for the domestic sector which were published between 1989 and 2000. The year of the projection refers to the year it was published, the actual projections usually start a few years before that date, because they begin with the latest actual energy use data available to the researchers at the time they created the projections. The projections are provided for five or ten yearly intervals, and linear projections have been made (by the author) between these years.

It would be wrong to put too much weight on precise comparisons between the projections without more detailed analysis, because there have been some methodological changes over the period. For example, in 2000 figures were only provided for the two 'central' scenarios, rather than the six variations calculated in previous years. Bearing that warning in mind, it is still worthwhile discussing how the projections have changed over time.

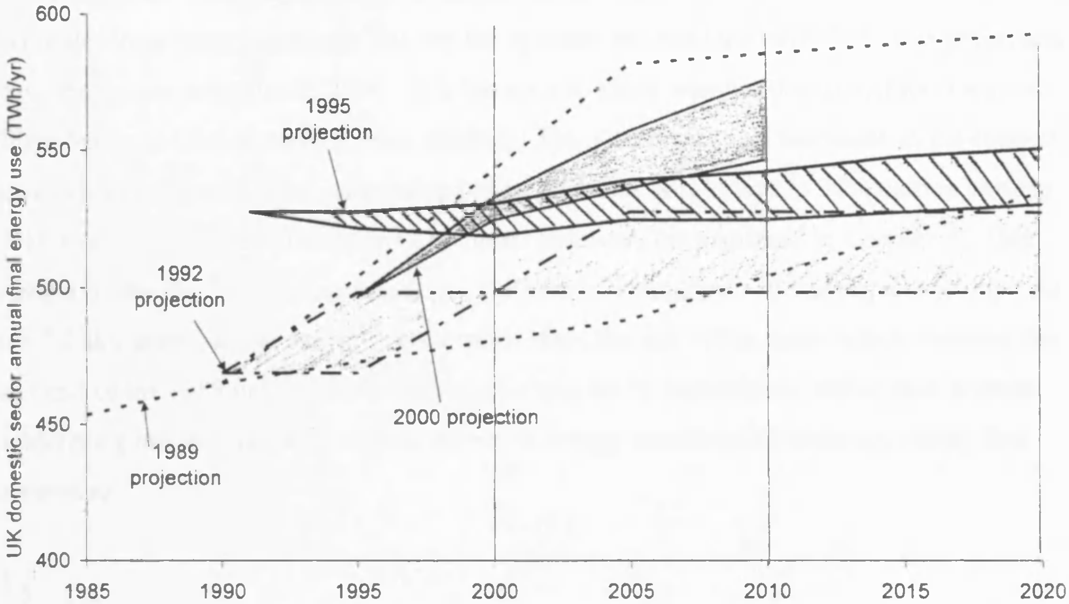

Figure 3.1: Various DTI projections for annual final energy consumption in the UK domestic sector up to 2010/2020

Sources: DTI 1989, DTI 1992, DTI 1995, DTI 2000

It is striking that there is little or no overlap in the range of projections for 2010 published only a few years apart in 1992, 1995 and 2000. With the exception of those published in 1989, the projections for 2020 or 2010 occupy a rather narrow range. Since 1992, projected energy consumption has been increasing.

Having compared the projections, it is useful to compare them with actual energy use over the period (Figure 3.2). For clarity, the 1992 and 1995 projections are excluded from Figure 3.2. A provisional projection to 2010 published in 2003 is also included in this graph. This 2003 projection[1] includes the expected effects of policies designed to reduce carbon dioxide emissions, but only one 'central' projection has been provided. A full set of new energy projections is awaited from DTI.

Since 1992, projected energy consumption has been increasing, however not sufficiently to keep up with what actually has happened. Present consumption is higher than the ranges projected in 1992 and 1995, and indeed in 2000. Projections made in 2000 did not include the expected effects of Climate Change Programme policies that were designed to reduce carbon emissions

[1] A provisional update of carbon dioxide emissions projections was produced in 2004, but details of final energy were not included in this document, so 2003 remains the latest available energy projection. (DTI 2004d).

(DETR 2000a). As a consequence, the 2000 projection would have been expected to have been higher than actual energy consumption, but the opposite has been the case. The 2003 projection expects energy use to reduce to 2010 – it is too soon to know whether this expectation will be fulfilled, but recent trends make it seem unlikely. The 2003 projection was made in the context of government expectation that its existing policy measures would lead to 20% carbon savings by 2010 from 1990, a view it not shared by many observers (as discussed in Chapter 2). This may explain why the 2003 projection seems 'optimistic' compared with subsequent reality. As Figure 3.2 illustrates, actual energy consumption since the late 1990s most closely matches the upper limit of the 1989 projection. However, this may be by coincidence, rather than because the underlying model represents current drivers in energy consumption more accurately than later versions.

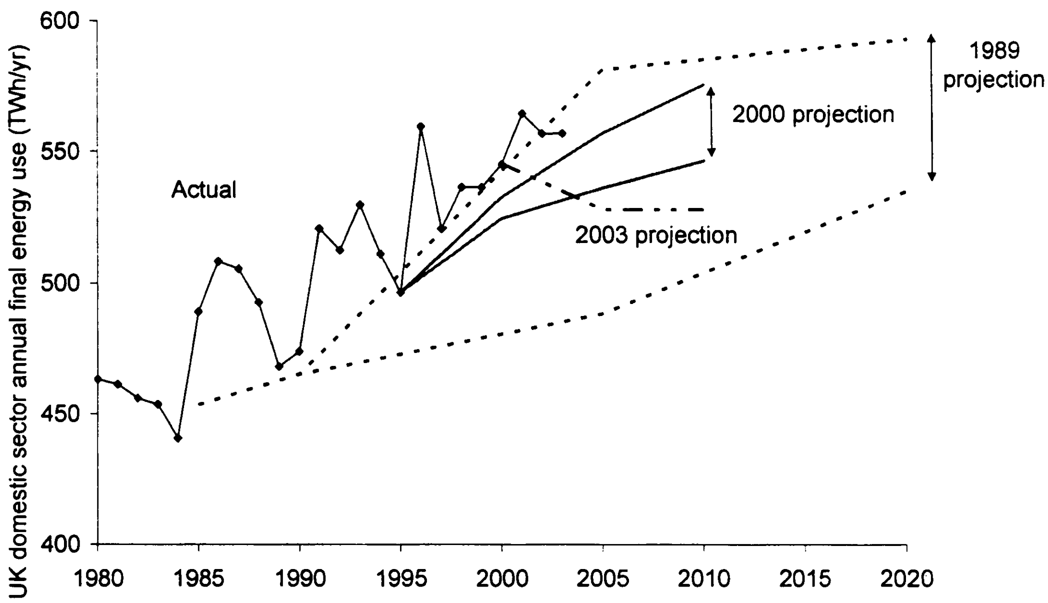

Figure 3.2: Annual final energy consumption in the UK domestic sector, actual figures 1980-2003 and three DTI projections up to 2010/2020

Sources: DTI 1989, DTI 2000, DTI 2004a, DTI 2003c

The difference between subsequent reality and these professionally researched and relatively short-term projections, substantiates the introductory remarks about the difficulty of predicting future energy use. All four projections since 1992 have underestimated actual energy consumption. Given that the projections are designed to underpin policy making, this suggests they will have encouraged less vigorous policy on energy reduction than was necessary to make the relevant savings. For risk-averse policy making, a wider (and more accurate) range of projections would seem to be required.

3.5 Bottom-up projections of energy use

3.5.1 What they are

Bottom-up modelling techniques are based on a different understanding of energy use from top-down models. Bottom-up models consist of highly disaggregated, physically-based data and relationships. They can be used for both the energy demand and supply sectors. The data input required for demand side models largely consists of quantitative data on technologies, efficiency, ownership, usage and lifetime of energy-using equipment and the physical characteristics of the housing stock. Economic variables, such as income and fuel prices, are not explicitly modelled within bottom-up methods. There is a systematic problem in bottom-up modelling, which is that new uses of energy which have not been invented at the time of modelling cannot be included, so bottom-up models are likely to underestimate future energy demand.

Bottom-up models tend to be used for different purposes than top-down projections. Bottom-up modelling is used by many different researchers to demonstrate the detailed possibilities for saving energy or reducing carbon dioxide emissions, usually as a result of improvements in energy efficiency (Table 3.1). The results of such research can influence policy makers. For example, the recent study from Imperial College (ICCEPT 2002) has been credited as being important to the government, with Tony Blair speaking about it in glowing terms in an environmental speech (Blair 2003). He particularly stressed the fact that the report promised 60% savings without huge shifts in the economy or significant changes in lifestyle.

3.5.2 Current projections

Several recent UK bottom-up studies concerned with household energy use are summarised in Table 3.1. For this thesis, the two most important models are that created by BRE (Shorrock & Dunster 1997) and Johnston's model (Johnston 2003a) which is based on that of BRE. These are discussed in much more detail in Chapter 4. The methodology of the studies differs, some look at measures which are economically favourable as well as technically feasible and for which policy suggestions are presented, whereas others include all technically feasible solutions. However, each is based on detailed bottom-up modelling and relies primarily on energy efficiency measures to make savings, so there is an important degree of commonality.

Table 3.1: Recent bottom-up energy studies and the potential for savings identified

Study	Year	Country	Energy sector	Savings*
BRE study 1 (Shorrock & Dunster 1997)	1997	UK	Household energy use	14% energy saving 2020 compared with 1995.
University of Oxford 1 (DECADE 1997)	1997	UK	Electricity for lights and appliances	28% electricity from 1996 to 2010
University of Oxford 2 (Fawcett, Lane, & Boardman 2000)	2000	UK	Electricity and gas domestic lights, appliances & water heating	17% carbon /13% energy from 1998 to 2020
BRE study 2 (Shorrock et al. 2001)	2001	UK	Household energy use	17% energy saving 2000-2020 under their 'efficiency' scenario
Energy Saving Trust submission to PIU energy review (Epple 2001)	2001	UK	Household energy use	12.5% energy saving 2000-2010, a further 12.5% 2010-2020 (24% 2000-2020)
European Climate Change Programme (Anon 2001)	2001	All EU	All sectors	16% greenhouse gases from 1990/1995 to 2010
Imperial College study (ICCEPT 2002)	2002	UK	All sectors	60% carbon savings by 2050
German study (Thomas et al. 2002)	2002	Germany	All sectors of the economy, gas and electricity.	Approx. 10% energy saving from 2002 to 2010.
David Johnston (Johnston 2003a)	2003	UK	Household energy use	50% energy and 61% carbon from 1996 to 2050

* Note: Studies often also give figures compared with a 'reference case' or 'business as usual' scenario, however, in this table only savings compared with actual energy consumption / carbon emissions in the stated year are reported.

Given the methodological differences between the studies, it would be misleading to compare their results in much detail. However, the overall conclusion is that both in the near and far term, there seem to be considerable technical opportunities for energy and carbon savings which have been identified and quantified using bottom-up methodologies. The UK studies in Table 3.1 show a range of potential energy savings from the domestic sector between 1995/2000 and 2020 of between 13% and 25%. In many cases specific policy suggestions have been made on how to secure the savings.

Rather than comparing these very recent studies with actual energy use, earlier bottom-up energy projections are compared with subsequent reality in the following section.

3.5.3 Lessons from earlier bottom-up studies

A considerable number of energy projections and scenarios have been created during recent decades. Of these, two important, detailed UK studies from the late 1970s / early 1980s are briefly presented and their projections are compared with what actually happened to energy use in the domestic sector. The two studies are:

Leach, G. et al (1979) A low energy strategy for the UK.

Olivier, D. et al (1983) Energy efficient futures: opening the solar option.

These studies have been chosen because they are both bottom-up studies, which used very similar approaches and techniques to those used in current studies looking at the potential for saving energy or carbon (e.g. Fawcett, Lane, & Boardman 2000, Johnston 2003a). In fact, both also have elements of other types of modelling. Leach et al includes explicit modelling of economic factors and Olivier et al includes both socio-economic scenarios and bottom-up modelling. The point of comparing the scenarios with what actually happened is not to point out 'mistakes' made by the authors in their projections or assumptions, rather it is to reflect on what can be learnt from past studies, twenty or more years on. Both studies looked at all sectors in the economy, but only the domestic sector is discussed here.

A low energy strategy for the UK (Leach et al 1979)

The intention of Leach et al was to demonstrate systematically, and in detail how the UK could have 50 years of prosperous material growth and yet use less primary energy than it did at the time of writing. Two scenarios were developed: high and low. The difference between them was the assumed rates of GDP growth (GDP roughly doubles by 2025 in the Low case, and trebles in the High case), which in turn affected the detailed sectoral assumptions. The scenarios were based on comprehensive bottom-up modelling.

Key domestic sector assumptions included:

- within 30 years all existing dwellings would have loft and cavity wall insulation
- building regulations ensure that the heat loss standard for 1990 homes is 50% that for 1975 homes
- electric and gas heat pumps reach mass market production in the 1980s and take 15% of space heating market by 2000
- major electrical appliances (cookers and white goods) halve their energy consumption between 1975 and 2010.

Energy-efficient futures: opening the solar option (Olivier et al 1983)

Olivier et al's report, the result of four years work by a team of people, aimed to provide a wide range of scenarios as a reference point for a discussion of alternative policy options. Four scenarios were presented: two of them (A1 and A2) were 'technical fix' futures, based on rising material living standards and high economic growth. The other two (B1 and B2) were 'conserver society' futures, based on a lower economic growth rate, the emergence of a 'post-industrial' economy, and the development of less environmentally damaging lifestyles. Scenarios A1 and B1 were based on a relatively vigorous exploitation of energy efficiency improvements and renewable energy systems; the other two (A2 and B2) assume slower change in these directions. The kernel of all four scenarios was an energy policy whose highest priorities were: (1) a rapid and wide-ranging programme of improvements in energy efficiency; (2) a gradual phasing-in of renewable energy sources.

To give a flavour of the degree of change envisaged, the following assumptions were included in scenario A1:

- In new 1990s houses, very good insulation and basic passive solar design features reduce space heat demand by 95% relative to the building regulations current at the time of writing.
- Post-2000 construction is sufficiently heat-tight to have negligible space heating demand; internal heat gains and passive solar provide virtually all the heat needed to keep buildings warm and comfortable in the UK climate.

Comparison with what actually happened

Domestic energy scenarios are shown in comparison with what actually occurred (Figure 3.3). Energy consumption has increased 1975-2000, so that consumption in 2000 was 26% higher than in 1975, whereas Leach et al suggested a reduction of 36% could be achieved. The highest and lowest Olivier et al scenarios, B1 and A2, show a range which falls lower than Leach at al in 2000 and beyond. Scenario A2 projected energy use in 2000 to be just one third of what it actually was in reality.

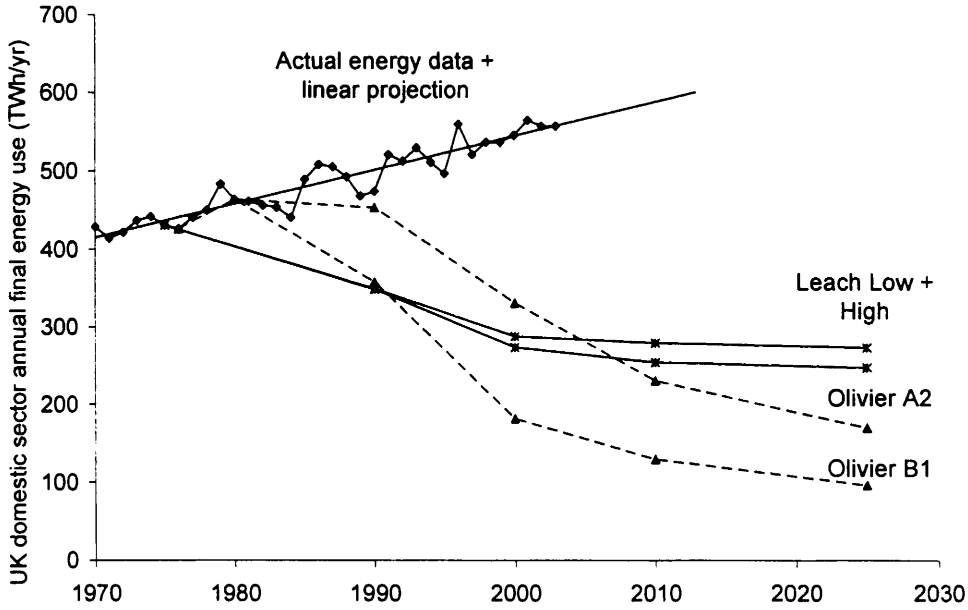

Figure 3.3: Comparison of projections for domestic energy sector UK, 1975-2025, with actual energy use, 1975-2003

Sources: DTI 2004a, Leach et al. 1979, Olivier et al. 1983

Discussion

The fact that these scenarios bear little relation to what has happened to domestic energy use should not reflect negatively on their authors. Their scenarios were not intended to be predictions of the future, they were meant to illustrate what might have happened had the UK tried to be a low energy economy - which it manifestly has not. Nevertheless, it is still worth asking why the energy use projections for 2000 were so much lower than what actually happened.

Some of the key values in the projections for each scenario are compared with what has actually happened (Table 3.2).

Table 3.2: Comparison of projections by Leach et al and Oliver et al with actual values

	Projections	**Reality**
Houses with cavity wall insulation (%)	100% by 2010 (Leach)	23% in 2001 (Shorrock & Utley 2003)
Accessible lofts with loft insulation (%)	100% by 2010 (Leach)	94% in 2001 (Shorrock & Utley 2003)
Space heating provided by heat pumps	15% by 2000 (Leach)	Almost zero

Appliance energy consumption (cookers, fridges and freezers, washing machines, dishwashers, dryers)	Half of 1975 value by 2010 (Leach)	No significant change to efficiency of hobs, ovens and kettles. Efficiency of most white goods improved (Fawcett, Lane, & Boardman 2000). But UK electricity consumption by domestic lights and appliances increased by around 75% between 1975 and 2001. (Shorrock & Utley 2003)
Heat loss standard for buildings	Half of 1975 value by 1990 (Leach)	Building Regulation heat loss standards (U values) for walls and roofs were less than half the 1976 standard by 1990. This led to the overall heating energy requirement being one third lower in 1990 than in 1976. (Chu & Oreszczyn 1991)
Heating requirement of new 1990s home	95% lower than that of new homes in early 1980s (Oliver)	Heating requirement for 1990 standard new home about 20% lower and for 1995 new home around 40% lower than in 1982. (Lowe & Bell 1998)
Heating requirement of post-2000 homes	Near to zero (Olivier)	2002 new homes should use around 25% less energy than in 1995. Nowhere near to zero. (ODPM 2004)

Of all these projections, the two matched in reality were the Leach et al target for loft insulation and the improved heat loss standards for dwellings between 1975 and 1990, otherwise the energy efficiency targets modelled have not been achieved.

The key differences between scenarios and reality were:

- scenarios assumed far greater take-up of existing energy efficiency technologies, such as cavity wall insulation, than has been the case;
- scenarios assumed more advancement of emerging energy efficient technologies, e.g. heat pumps, super-insulated houses than actually occurred;
- because new uses of energy cannot be anticipated and included in bottom-up projections (as the authors recognised) the scenarios underestimated consumption from new electrical goods.

The methodology for undertaking a bottom-up projection over the last twenty years has changed very little. One difference is that a 'business as usual' projection is now usually included in modelling exercises. In addition, there is now more data available on the ownership and usage of end-use equipment in the home. Previous experience with modelling such as this should give pause for thought when faced with optimistic technologically-based assessments of potential savings. Current energy saving projections are no less vulnerable to the issues identified above than earlier exercises, i.e. there is no real evidence that lessons have been learnt.

3.6 Scenarios

3.6.1 What they are

The word 'scenario' has been used earlier to describe future projections generated by top-down or bottom-up models. In this section 'scenario' has a more specialised use, as described by Gallopín & Raskin:

"*Scenarios are stories about the future with a logical plot and narrative governing the manner in which events unfold. ...Compelling scenarios need to be constructed with rigor, detail and creativity, and evaluated for plausibility, self-consistency, and sustainability. ... Scenarios also clarify alternative worldviews and values, challenge conventional thinking, and encourage debate. Since they embody the perspectives of their creators, either explicitly or implicitly, they are never value-free.*" (Gallopín & Raskin 2002:10)

This definition of scenarios describes well the types of scenarios developed for the UK as Foresight Scenarios (SPRU 2002) and internationally by the IPCC (2001b). Scenarios are different from bottom-up and top-down models in that they are only ever about the future, whereas bottom-up and top-down analyses are descriptions of the past and present, which can be used to look forward to the future.

3.6.2 Current scenarios

Two scenario exercises are discussed in detail. The first, the "Foresight" scenarios, are for the UK. The other detailed account is of the IPCC's global scenarios. In addition, a brief description is given of other scenario exercises, which differ significantly from these two.

Foresight scenarios

The UK's national Foresight Programme has developed four scenarios of environmental futures for 2010 - 2030, which were first published in 1998 (Office for Science and Technology 1998) and updated in 2001 (SPRU 2002). The Foresight scenarios have been framed in the context of two basic dimensions of change: social values and governance systems (Figure 3.4). The social values dimension takes account of social and political priorities as well as the economic patterns resulting from them. At one end of the spectrum 'individual' values are dominated by economic and political liberalism, at the other end 'community' values are shaped by a more communitarian ethic emphasising social networks and responsibility. The governance system dimension represents the structure of political authority and decision-making. The two extremes are characterised as 'interdependence' and 'autonomy'. For interdependence political power is distributed away from national governments, both upward to supra-national bodies and downwards to regional government. Autonomy indicates that public and private decision making is largely retained at the national and regional level within the UK.

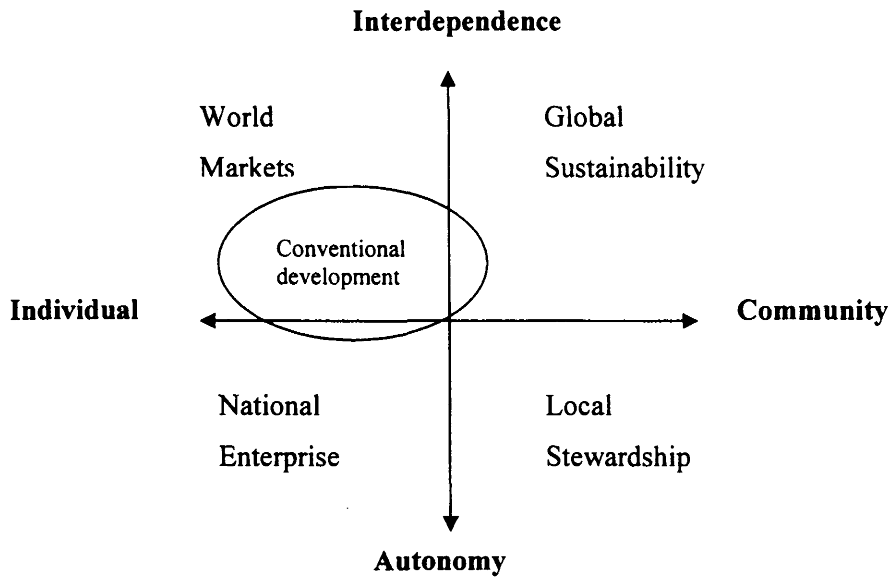

Figure 3.4: Foresight environmental scenarios for the UK

These dimensions are taken as axes which define the four scenarios: World Markets (interdependence and individual), Global Sustainability (interdependence and community), National Enterprise (autonomy and individual) and Local Stewardship (autonomy and community).

The Foresight scenarios have been used by PIU to investigate whether 60% carbon savings could be achieved by 2050 (PIU 2002). They showed that 60% reductions are only achieved in the Global Sustainability and Local Stewardship scenarios – i.e. in those with changed social priorities where sustainability is a driving force (Table 3.3).

Table 3.3: Carbon dioxide emissions, preliminary estimate, UK, 2050

Scenario	Annual carbon emissions (MtC)	% change from 2000
2000	138	
World Markets, 2050	166	20%
National Enterprise, 2050	150	9%
Global Sustainability, 2050	54	-61%
Local Stewardship, 2050	55	-60%

Source: PIU 2002

The Global Sustainability (GS) and Local Stewardship (LS) scenarios both achieve 60% reductions although by very different means. GS requires extensive use of hydrogen and some carbon sequestration, in addition to major increases in renewable energy use and energy efficiency. LS achieves 60% reductions because of lower economic growth and social change. PIU note that WM and NE could not achieve a 60% decrease in carbon emissions even if they had carbon-free electricity generation.

IPCC

The Intergovernmental Panel on Climate Change has created four 'families' of scenarios (neutrally named A1, A2, B1, B2), which encompass four combinations of demographic change, social and economic development, and broad technological developments (IPCC 2001b). Figure 3.5 gives a brief overview of the scenarios, with A1 featuring high levels of economic growth and globally based activity and little concern for the environment, contrasting with B2 which features more regionally based economies and high levels of environmental concern. Three scenarios have been developed for the A1 family which explicitly explore energy technology developments at the same primary energy demand: A1FI which is fossil-fuel intensive, A1T which is non-fossil fuel intensive, and A1B a 'balanced' mix of fossil and non-fossil fuel energy. IPPC state that there is no single central or "best guess" scenario, and probabilities or likelihoods are not attached to individual scenarios. None of the scenarios includes any action to combat climate change.

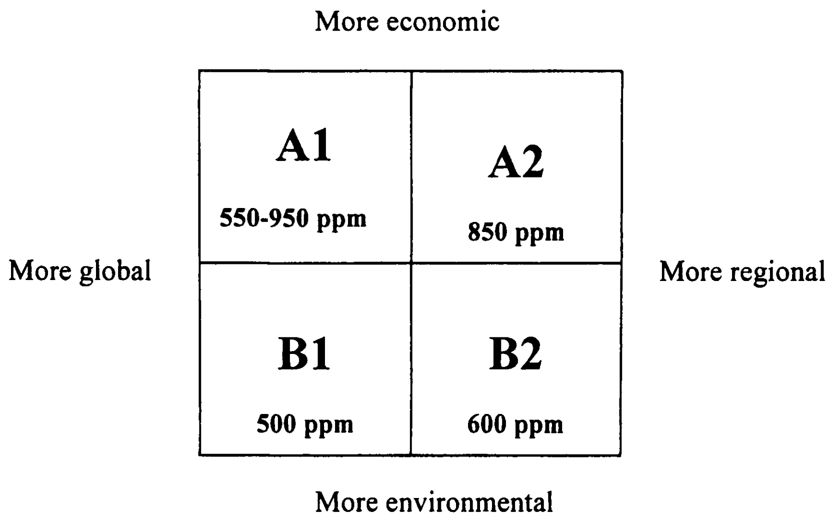

Figure 3.5: IPCC scenarios for energy use and carbon dioxide emissions, showing carbon concentrations in the atmosphere by 2100

The projections for primary energy demand vary four-fold between the different scenarios, with the A1 scenarios having four times the energy demand of B1. In all cases there is growth from

1990 levels, the lowest level of growth being in B1 where energy demand in 2100 is about one and a half times what it is today. The differences in primary energy demand and the types of energy used to meet the demand translate into a range of carbon emissions, with the carbon dioxide concentrations in the atmosphere by 2100 varying between 500ppm and 950ppm depending on the scenario. So, without action to reduce carbon dioxide emissions, IPCC do not foresee a scenario whereby atmospheric CO_2 concentrations are below 500ppm in 2100. Although IPCC do not attach probabilities to any of their scenarios, A1F1 which generates the highest emissions at 950ppm by 2100 is the scenario which is, in the author's view, most like 'business as usual' development of current trends.

Other scenarios

Two other scenario exercises, which differ considerably from the IPCC and Foresight scenarios, are described briefly. Shell, who pioneered the use of scenarios in the 1970s, have developed two scenarios for the global energy system which halt the rise in carbon dioxide emissions by 2050 leading to a stabilising of atmospheric carbon levels below 550 ppm (Shell International 2001). The scenarios contrast an evolutionary progression from coal, to gas, to renewables (or possibly nuclear), 'Dynamics as Usual', against the potential for a hydrogen economy supported by developments in fuel cells, advanced hydrocarbon technologies and carbon dioxide sequestration, 'The Spirit of the Coming Age'. World primary energy demand from 2000 to 2050 would double in Dynamics as Usual and almost triple in The Spirit of the Coming age. The contribution of energy from hydro, biofuels and other renewables would increase in those fifty years by a factor of eight and ten respectively. The Shell scenarios are very technologically optimistic. Indeed, they have a very clear agenda - which is to show that business will be able to restrict the damage from climate change through technology. They are unique in identifying a business as usual scenario which results in stabilised carbon emissions.

Gallopin and Raskin (2002) look at a broader range of scenarios than Shell. They present three basic scenarios, Conventional Worlds, Barbarization and Great Transitions, for each of which two variations are outlined. Conventional Worlds scenarios offer visions of gradual adjustment and essential continuity of future values and institutions with those of the industrial era. Barbarization scenarios consider the grim possibility that the march of conventional globalisation is knocked off course by a general crisis. Great Transitions are scenarios in which global society undergoes profound change in response to planetary challenges. This would be a values-led shift towards an alternative global development vision which would focus on values such as spiritual, cultural and intellectual fulfilment, quality of community and enjoyment of nature. In contrast to Shell, the authors see no possibility of restricting carbon emissions under business as usual (Conventional Worlds) development. Current trends will not 'bend the curve' of development toward an environmentally and socially sustainable global future.

Discussion

The scenarios mapped out in the Foresight exercise and by IPCC are based on similar axes defined in one dimension by the geographical integration of economic and political activity and in the other by varying social values. Thus, there is an equivalence between A1 and World Markets, A2 and Provincial Enterprise, B1 and Global Sustainability and B2 and Local Stewardship. In the Foresight studies it is only those scenarios with changed social values (towards environmental values) which can achieve significant carbon savings. However, according to IPCC, a business as usual scenario which incorporated very high levels of renewable energy or nuclear (A1T) could result in emissions almost as low as those from the more environmentally focused scenario B1. In the UK, a significant additional contribution to national energy supplies from either nuclear or renewable energy within the next twenty years seems extremely unlikely (Hillman & Fawcett 2004).

The scenarios developed by both Foresight and IPCC which generate highest emissions (World Markets and A1) are those which most closely follow current trends. IPCC and Foresight have failed to imagine a world which could be worse in terms of climate change than a continuation of recent patterns of development. Not only does this underline the importance of developing in a different way from 'business as usual', it also suggests that the true 'worst case' scenario could be even worse for the environment than those envisaged by IPPC and Foresight. There might be even more destructive patterns of development than those underway today, which could result in greater climate change more quickly, delivering a worse future than currently imagined.

3.7 Comparison of modelling methods

The three key methods of modelling energy futures have now been reviewed individually. This section compares top-down and bottom-up modelling, and then bottom-up modelling with scenario methods. The extent to which these methods are complementary or contradictory is debated.

3.7.1 Contrasting top-down and bottom-up modelling

Creating a model is a way of understanding the world. Economists tend to favour top-down models that do not explicitly include technology; technologists favour bottom-up models that do not explicitly include economic factors such as the price of energy. Given the different understandings of the world they embody, can top-down economic models and bottom-up technical and stock models both be equally valid? Are they complementary or contradictory ways of understanding the same phenomena?

There are good arguments to suggest that these types of model are complementary. Shorrock and Dunster (1997) write that: "*... the factors that feed into econometric models and physical models are not independent - they are simply different ways of describing the same phenomena.*" They go on to argue that although physical models do not explicitly include household income, this is indirectly included in the model through its effects on the energy using equipment that people own and how they use it. In addition, there is a degree of interaction between bottom-up and top-down models. For example, the DTI use numbers generated from bottom-up modelling by the DECADE team at the University of Oxford in their econometric model (DTI 2000). This suggests the modelling methods can be complementary rather than contradictory.

On the other hand, Shorrock and Utley, authors of the Domestic Energy Fact File series, state that their modelling shows that energy prices have had no effects on energy consumption over recent decades:

"Fuel prices, income and energy expenditure are considered ... and it is shown that, overall, fuel price variations have not had much direct effect on domestic energy use over the past thirty years or so. Rather, physical factors ... offer the best explanation of the observed pattern of domestic energy use." (Shorrock & Utley 2003:17)

According to this analysis, physical bottom-up modelling is sufficient to understand what has happened, and, by implication, what will happen in the future. There has been no response by the DTI to this assessment (Shorrock 2004). However, price is only one component of econometric modelling, and lack of price sensitivity (over the range experience in the past 30 years) clearly does not mean economic factors have no influence on energy use.

The different world views encompassed by top-down and bottom-up modelling approaches can have consequences in terms of policy prescriptions. In top-down models, the price of energy is a key determinant of energy consumption and modifying price is naturally seen as a key policy instrument. In contrast, those who create bottom-up models are likely to suggest a diversity of detailed technical improvements which can be brought about by various policy instruments rather than energy taxation.

3.7.2 Contrasting scenarios and bottom-up modelling

Scenarios and bottom-up models are designed to do somewhat different jobs. The general approach in bottom-up studies is to contrast a business as usual projection, with one where many efficiency measures are introduced. The efficiency projection is based on the same patterns of ownership, usage and service standards as in the business as usual case. In other words, only technology changes and lifestyles remain unaltered. However, this understanding of future possibilities contrasts with that offered by the Foresight scenarios, and other scenario exercises, whereby the types of technologies adopted and the energy savings made depends on social values. PIU (PIU 2002) suggest that only in futures where sustainability is an important social goal will significant carbon savings be made. The difference between these types of future vision arises because bottom-up projections are designed to illustrate the possibilities for change that technology offers rather than to provide a comprehensive and coherent picture of possible future worlds. Bottom-up models cannot represent society.

However, if insights from the scenario approach about the linkage between technologies, social values and lifestyles are not incorporated into bottom-up projections then the technology improvement scenarios may be misleading. Why would radical technological solutions (such as external cladding of solid wall properties or solar water heating) be implemented in the absence of equally radical social change? Though technological solutions are plausible in terms of the technology, economics and policies to introduce them, they can lack plausibility in terms of a believable future society. The technological improvement scenarios offered by bottom-up studies are thought to be uncontroversial because they do not challenge current trends in ever-increasing demand for energy services. However, arguing for a technology-based approach alone is not a 'value-free' position: it defends the current values of unrestrained economic growth and non-intervention in consumption, values which may not be compatible with sustainable development or significantly reduced carbon emissions (SDC 2003).

3.7.3 Discussion and implications for this research

All types of modelling have limitations. Attempting to look fifty years into the future is in itself an exercise which is problematic. However, the justification for this time scale is two-fold. Firstly, it acknowledges the long-term nature of the problem. The government has already set a carbon dioxide reduction target for 2050, which makes the same point. A long-term strategy for reducing carbon emissions is required. Secondly, a long-term vision is important to ensure that actions taken in the near future do not preclude further savings in future. This is particularly the case for housing, where houses built today are likely to last for hundreds of years (see Chapter 4). Long-term analysis provides the framework for better short-term policies.

One of the two key questions posed in this thesis is whether improvements in energy efficiency can lead to savings of 60% by 2050. Econometric models have been shown to have a poor record of projecting future energy use over the short term (10-20 years). Further, it is doubtful that trying to find out whether 60% carbon savings could be achieved by 2050 is a legitimate question for top-down models. This is not the sort of question they are designed to answer.

Bottom-up modelling presents the best basis for analysing the prospects for sector-wide savings from energy efficiency. Using a bottom-up model to look forward this far in the future has many limitations, not least that errors in projections will increase considerably over time. Section 3.8 discusses in detail the limitations of trying to model savings from energy efficiency.

In order to draw on experience from scenario exercises, the bottom-up model created in Chapter 4 will be used to investigate different social scenarios. Two scenarios, High Energy and Low Energy, will be created. The social values implicit in these scenarios will align with 'individual' (High Energy) and 'community' (Low Energy) values, as described in the Foresight scenarios.

3.8 The problems of modelling savings from energy efficiency

3.8.1 Introduction

Evidence in this chapter and Chapter 2 has shown that, while savings from energy efficiency measures can be calculated, this may bear no relationship to the saving which are subsequently achieved in reality. This section first takes a closer look at the problems of modelling savings from energy efficiency. Following this, the limitations of focusing on individual properties rather than the wider housing stock are considered.

3.8.2 Modelling problems

The problems can be categorised as:

- Data problems – difficulties in making future estimates to use within models
- Modelling problems – inherent problems with bottom-up modelling and the relationship between energy use in models and in real life
- General problems.

These are discussed in turn below, with a focus on the risks of over-estimating the potential for savings from improvements in efficiency.

Data problems

To create future projections in bottom-up models, assumptions have to made about the development of efficiency in existing and new products, ownership and usage over time of each individual technology modelled.

Analysis of early modelling studies shows that the key energy saving options and technologies have barely changed over the past 20-25 years (this is also illustrated by comparing two 'homes for the future' designed twenty years apart, see Appendix 1). Some technologies which it was hoped would make a contribution to energy saving, such as solar water heating and heat pumps, are still only minor players, whereas other technologies for which there was previously optimism, such as district heating and solar heating, have not materialised and are unlikely to make major impacts without significant government support in the UK. No significant new energy-saving technologies have been introduced over the past twenty or so years, although the efficiency, attractiveness and cost effectiveness of many, e.g. compact fluorescent lamps (Palmer & Boardman 1998), has improved greatly. In modelling, significant efforts are often put into looking for potential new energy saving technologies (e.g. heat pumps, micro-CHP), whereas history shows new energy using technologies, such as PCs and digital entertainment equipment, and greater use of existing technologies have so far been much more influential on energy use. There is always the danger that hope and enthusiasm for new technologies, particularly at an early stage of development, will outpace what they subsequently deliver.

In order to calculate efficiency savings, estimates have to be made of the rate of take up and ultimate extent of take up of more efficient technologies. If estimates are based on the assumption that people will act in their own economic interest and take up efficiency options as quickly as possible and that the ultimate level of take up will be determined by the number of households for which it is cost effective, savings will be over-estimated. As Wade & Leach state:

"*The lack of take up of well-proven and cost-effective energy efficiency technologies is a familiar problem, yet it is one for which the solution remains elusive.*" (2003:133)

Take up rates in reality can be slow. Shorrock and Utley (2003) use historic ownership data of hot water tank insulation, draught proofing, loft insulation and other measures to estimate likely future trends for individual measures. Their analysis shows that at present rates of growth it might take until 2050 before cavity wall insulation is present in all homes for which it is suitable. It also demonstrates that even the fastest growing markets can take around thirty years to reach saturation.

The future use of technologies has to be estimated in sufficient detail to allow future energy consumption to be calculated. So, for example, for washing machines the number of uses per year at each temperature must be estimated. Such estimates will be created with reference to past data and trends in washing machine usage, projections of number of people per household, trends in fabrics and their required washing temperatures and washing powders and so on.

The most difficult aspect of estimating the future usage of technologies lies in understanding the relationship between changing technology, particularly increases in efficiency, and consequent changes in usage. It is widely acknowledged that energy efficiency improvements can be used to gain more energy services rather than to reduce energy use, a phenomenon known as take-back. The key end use where take-back occurs is space heating. Evidence shows that the colder people's homes are prior to efficiency improvements, the more of the gain in efficiency they take back as increased warmth (Milne & Boardman 1997). The government assumes that people in fuel poverty will take 75% of the benefits of better heating systems and improved home insulation to increase heating levels (DEFRA 2004b). On the other hand, there is evidence that replacing ordinary lighting with energy efficient lighting does not significantly increase hours of lighting use (DECADE 1997). Thus the amount of take-back seems to depend on unmet needs or wants; there is no universal rule.

Modelling problems

The inability of bottom-up modelling to anticipate new uses of energy, as already mentioned, is a well-known but nevertheless serious limitation of these models. New uses of energy already on the horizon include domestic air conditioning, outdoor space heating, high power showers, and increasing uses of digital entertainment equipment, and all of these have the potential to lead to considerably increased energy consumption in the domestic sector.

Research shows that expected savings from energy efficiency have often been over-estimated, in comparison with subsequent monitored savings. By contrast, the author does not know of any research which shows unexpectedly large savings from energy efficiency schemes or policies. There can be many different reasons for real-life energy savings being less than those modelled, including:

- Failure of real life efficiency to match that achievable in theory for many different reasons, e.g. substandard installation of efficiency measures such as insulation
- take-back of savings as increased service (discussed above)
- unexpected behaviour by householders
- faults in modelling (where the data inputs are correct, but the model is flawed).

Henderson et al. (2003) analysed monitored data on energy consumption in electrically heated households before and after energy saving interventions under the 'EESOP1' (Energy Efficiency Standards of Performance) programme which operated from 1994 to 1998. The energy efficiency measures installed varied by household, and included cavity wall insulation, loft insulation and efficient light bulbs. They found that the savings monitored were about half of those expected. Their hypothesis is that this is primarily because standards of heating in the properties were lower than modelled (both before and after interventions) so that the expected savings were not there to be made. Thus in this case the assumptions which informed the modelling were likely to be at fault.

Oreszczyn (2004b) explains how the modelling of the energy characteristics of conservatories varied very considerably from their real life usage. Initially, modelling suggested that the addition of a conservatory could lead to saving of around 5% (or 1,000kWh) of the heating energy requirement of the house. However, research demonstrated that in reality people were heating their conservatories, rather than using them as unheated spaces as had been assumed. Heating a conservatory attached to a new house can almost double the heating load (Chu & Oreszczyn 1991). In this case unexpected behaviour led to the initial discrepancy between the modelled and real-life energy impact of conservatories.

As mentioned briefly already, there has been very little monitoring of energy use in UK households. The largest sample sizes have been around 100 (e.g. LEEP 1996). Without detailed monitoring of a significant sample of dwellings, there is little suitable data with which to validate the details of modelling. This increases the risk that, while models can correctly represent total UK energy use for the past and present, modelling of the individual components of energy use is incorrect. This will lead to poor future projections.

General problems

There are economic arguments which question the economy-wide effect of efficiency. Herring (2000) argues that improvements in energy efficiency will lower the implicit price of energy, and thus of energy services, hence stimulating demand for energy and energy services and resulting in increased consumption.

Finally, greater energy efficiency can be part of the process that creates new demand for energy consumption 'needs', where need is not a fixed standard, but is socially and culturally determined with yesterday's luxury fast becoming today's essential. Would heating the whole house, rather than just the living areas, have become common practice without more efficient central heating systems and better insulated houses? It seems unlikely. In this, energy efficiency is part of the broader technological and economic advance which is serving to bring energy-using equipment and activities (e.g. cars, central heating systems, long-distance holidays) within reach of most British people. It is very difficult to disentangle the role of energy efficiency in constructing these energy consumption 'needs', but there is little doubt it is playing a part in this process.

Conclusion

None of the factors listed above make it inevitable that bottom up models will lead to over-estimation of the savings from efficiency measures, except perhaps the last. However, in practice over-estimation has been common, and these factors should be acknowledged in future modelling.

3.8.3 The limitations of focussing on individual properties

Bottom-up modelling largely considers energy consumption and reductions possible at the level of the individual property. For existing housing, most energy efficiency options apply only to individual properties. However, for new housing schemes, larger scale issues such as orientation and built form, which affect the whole development, could have an effect on energy consumption. This section identifies possible demand-side energy and carbon reduction options which operate on a collective level.

Most examples of low energy (or low carbon) housing in the UK are single homes or very small developments of dwellings, and as such it is difficult to use existing empirical UK data to identify whether additional benefits are gained when low energy housing is designed on a larger scale. In addition, there are relatively few examples of low energy housing of any type, and even fewer examples for which monitored energy data is available (Johnston 2003a). Lovell (2003) reports that in the English East Midlands, which is considered one of the most innovative regions in the UK, low carbon housing formed just 0.08% of new housing built in the region in the period 1991-2000. The largest of the low carbon housing schemes Lovell identified consisted of less than fifty dwellings. Thus there are few UK examples which can be investigated to see whether and how larger groups of dwellings can save significantly more energy than single dwellings.

Probably the most celebrated sustainable housing development in the UK on a relatively large scale is BedZED in Sutton, London, constructed during 2000/01. BedZED is a compact mixed-use urban development with 82 housing units, with over 2500 m^2 of space for offices, studios, shops and community facilities. The housing is a mix of one- and two-bedroom flats, maisonettes and town houses and is laid out in three parallel terraces (Bill Dunster Architects 2002). A number of the energy features of BedZED can be replicated in single properties, e.g. super insulation, low energy lighting and efficient appliances, advanced glazing, use of conservatories to increase solar gain, PV cells providing electricity and solar shading in summer. However, other features were a function of the overall design and whole development, a terraced built form which minimises heat loss, orientation being organised so that one building does not steal sunlight from its neighbours, integration of work spaces to take advantage of north-facing aspect in a positive way, and wood-fuelled combined heat and power (CHP) providing carbon emissions-free hot water, heating energy and electricity. There has not yet been a full report on the performance of BedZED which identifies the contribution of different elements to its eventual energy use and carbon emissions. However, existing information on how built form and orientation influence energy consumption is discussed below.

The built form of a property can have a significant effect on its energy use. In the 1970's BRE carried out work looking at the energy consumption of dwellings with the same floor area but of different built form (Table 3.4). This showed that a detached house used more than twice as much heating energy as an intermediate flat, and 60% more than a terraced house. The work was repeated in 1995, by which time the difference in heating energy requirements of varying built forms was less pronounced, but still existed. However, the proposed standards for 2005 show very similar ratios of energy use by built form to those in 1975. The data demonstrate the difference built form can make to heating energy requirements, with flats being the most efficient built form and bungalows the least.

Table 3.4: Influence of built form on heating energy requirements for new properties of the same size

	Index of heating energy, detached house = 100		
	1975	**1995**	**2005 proposals**
Detached house	100	100	100
Bungalow	n/a	122	n/a
Semi-detached house	85	93	89
Top flat	71	n/a	n/a
mid-terrace	63	84	69
Intermediate flat	44	n/a	43

Sources: BRE 1975, ODPM 2004

Note: These calculations are on a slightly different basis as the 1995 and 2005 figures were initially calculated for the average floor area for properties of that built form and then normalised in this table, rather than being calculated from the start for properties of the same floor area as was the case for the 1975 data.

However, as Owens (1986) points out, flats and terraced houses usually serve a different sector of the market from detached homes. In general, 'moving up through the housing market' has meant moving to less energy-efficient built forms. However, this is not universally true within the UK, flats are more popular and represent a much greater percentage of dwellings in Scotland than in the other UK countries (Shorrock et al. 2001). The cultural and economic value attached to different built forms may not be fixed, but must be acknowledged.

A lot of work has been undertaken on the potential for passive solar gain to offset traditional space heating. In particular a great deal of work was done on this topic in the 1970s and 1980s, and this is when most solar housing projects were built (Taylor & Bruhns 1999). The research generally showed that the contribution of solar heating to a house's total energy use (as a result of specific solar design) was actually relatively small (Vale & Vale 2000).

In conclusion, the properties of individual dwellings are key to their energy efficiency. Built form is still important in influencing energy use. However, because of the social and functional differences between built forms, it is likely to be difficult to move towards more efficient forms for much of the housing market. The influence of orientation is lower than might be thought.

3.9 Summary and conclusions

A wide range of researchers and institutions use models to look at the future. Projections are created for different purposes: to illustrate possible futures, to show futures which should be avoided or encouraged, to help today's decision makers, to defend the status quo or to argue for change. The focus of this thesis is to identify means of reaching a preferable future.

Modelling based on quantitative methods is a long-established means for identifying carbon savings in the domestic sector. In the UK there is a lot of experience of producing calculations for suggested futures, but insufficient reflection on and analysis of past experience. DTI projections continue to underestimate future energy consumption. Given that the projections are designed to underpin policy making, this suggests they will have led to less vigorous policy than necessary to make savings. For risk-averse policy making, a wider range of projections than provided by this sort of analysis is required.

Many plausible and defensible technological projections for making savings have been developed, most of which look at a twenty year period. However, as for past exercises, these depend on widespread adoption of energy efficient technologies and the development of new technologies. Detailed analysis of earlier modelling and data from UK energy efficiency programmes shows how vulnerable assumptions about efficiency savings are. While this does not suggest that bottom-up modelling should not be undertaken, it does suggest much more attention should be paid to past experience, and that more conservative estimates of energy savings from efficiency should be employed. Further, insights from scenario modelling should be incorporated where possible. Most scenario exercises show that only a change in social values (towards sustainability) will result in 60% carbon or energy reductions by 2050, which brings into question the reliability of expected savings based on technical changes alone.

At present, the UK does not appear to be moving towards a lower carbon future. With the single exception of the Shell scenarios, all the business as usual projections referenced in this chapter, whether top-down, bottom-up or scenario-based, suggest that the UK will not achieve significant carbon reductions in the domestic sector within the next 20-50 years.

This chapter has identified the techniques most suitable for addressing the research questions of this thesis as bottom-up modelling with some contribution from scenario methods. The following chapter looks in detail at a particular bottom-up model, explores the savings it suggests are available from technological change, and demonstrates how these savings could be negated in a scenario where changes in behaviour lead to high growth in energy demand.

Chapter 4 – Modelling energy use and carbon dioxide emissions

4.1 Chapter overview

Chapter 3 has shown that many studies suggest considerable savings are still available from improvements in energy efficiency, while warning of the limitations of such estimates. The starting point for this chapter is Johnston's (Johnston 2003a) bottom-up modelling work which suggested carbon savings of 60% could be achieved by 2050 through efficiency improvements. Johnston's model was chosen because both the method and input data are fully publicly available via his PhD, and so it was possible to re-create this bottom-up model.

However, this chapter challenges the robustness of the projected savings, both in terms of the difficulties of achieving theoretical savings in real life, and under scenarios of increased demand for energy services. Variations in energy demand from social and behavioural / lifestyle changes are discussed in some detail. The key variables driving demand are: internal temperature, personal hot water usage, household size and consequently the number of households, the rate of demolition and replacement of old property, and energy use by lights and appliances. The combined effect of alterations in these variables is considered in 'High Energy' and 'Low Energy' scenarios, which demonstrate the wide range of possible future energy consumption. Under the 'High Energy' scenario, the energy saving technologies identified by Johnston would not be adequate to ensure a reduction of carbon dioxide emissions by 60% by 2050, indeed only 17% savings could be achieved. The 'Low Energy' scenario identifies non-technological routes to carbon and energy savings, which could exceed 60% by 2050.

Following this discussion of demand side influences on energy use and carbon emissions, there is a brief discussion of potential changes to the supply side mix of fuels used to generate electricity and to supply heat to the housing stock. The consequences for carbon dioxide emissions are outlined.

As well as presenting a bottom-up model and introducing new data and analysis, this chapter aims to add to the arguments in the previous chapter which challenge the credibility of projections of energy savings from existing models, leading to the conclusion that a new policy approach to achieving carbon savings is required.

4.2 Methodology

The analysis in this chapter is based largely on Johnston's (2003a) bottom-up model, the full details of which are explained in the following section. The energy projections from Johnston's model are presented, and analysed with respect to historic and more recent energy consumption data, taking into account external temperatures. His projections are also compared with linear projections to 2050 which are based on actual domestic sector final energy 1970-2003.

Johnston's model was recreated as an Excel spreadsheet model based on the details in his thesis. The re-created model was tested against the original to check that the outputs match, and errors were corrected. Where new data has become available since the original model was published, this is presented. Selected new data is combined into a new 'Tina Fawcett - business as usual' (TF-BAU) scenario and compared with Johnston's BAU scenario to identify the difference the new data make.

Barriers to the technological improvements Johnston investigated in his energy saving scenario are illustrated, by investigating key technologies in more detail. The key barriers, both technical and non-technical, to their adoption are outlined, both by comparison with past experience of technology adoption and other key factors.

The model was used to develop new scenarios based on social and behavioural change. The potential social and behavioural changes have been identified by focusing on changes that would have a major effect on energy use, analysing how these factors have changed over recent years and looking at experience in other countries. One of these factors is rates of demolition – and existing data sources have been combined to get a more accurate picture of current demolition rates. Another factor is internal temperature, and a comprehensive review of data on internal temperature in UK houses which combines modelled and monitored values from a number of different studies has been undertaken. In addition, theories of thermal comfort are described and used to gain insight into changing internal temperatures in the UK. Once possible future developments have been identified, the maximum and minimum values are combined together in two scenarios, to give a high energy and low energy scenario.

Finally, the future carbon intensity of energy sources in the UK is discussed. Secondary data is used to calculate the current carbon intensity of electricity. Existing projections of the carbon intensity of electricity from different sources are compared. The prospects for increase of the low carbon sources of electricity – renewables and nuclear – are outlined.

4.3 Johnston's model

4.3.1 Description

The model developed by David Johnston for his PhD research (Johnston 2003a) is a selectively disaggregated physically-based bottom-up energy and carbon dioxide emission model of the UK housing stock. The model covers both the energy demand and supply side and was used to develop three illustrative scenarios of energy use and CO_2 emissions. The model has been constructed around two separate but inter-related components: a data model and a BREDEM-based energy and carbon dioxide emission model (Figure 4.1). The BREDEM-based model is based upon the Building Research Establishment's Domestic Energy Model Version 9.60, which is used for SAP, the Standard Assessment Procedure method of energy rating individual homes (BRE & DETR 1998). Johnston had to create his own model because BREDEM and its associated database, together known as BREHOMES, although widely used in policy are not both publicly available, and so it is not possible to test hypotheses with them.

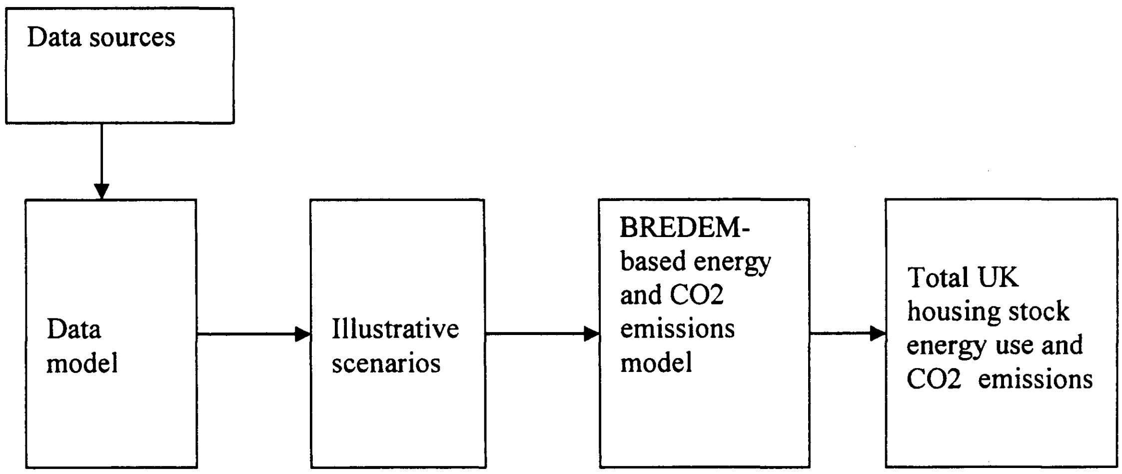

Figure 4.1: Structure of Johnston's model

A considerable amount of data is required for the model, including annual present and future values (1996-2050) for population, levels of insulation, ownership of appliances and various other energy related characteristics of the UK housing stock. Some figures are unchanged throughout the period e.g. overall dwelling dimensions – but most change each year. In order to simplify the amount of input data required, the model was constructed around just two 'notional' dwelling types: a pre-1996 'old' dwelling and a post-1996 'new' dwelling (1996 was the most recent year for which comprehensive data were available when Johnston began work on his PhD). This is much simpler than the BREHOMES model (based on BREDEM), which contains over 400 categories of dwelling defined according to age, built form, tenure and the ownership of central heating (Shorrock & Dunster 1997). Johnston's model does not include any data on tenure and makes a simplified assumption that the average built form is semi-detached.

Johnston constructed three main scenarios, with variations on the latter two:
Business as usual (DJ-BAU) – this scenario is based on BRE's 'reference case' scenario (Shorrock et al. 2001). It features gradual efficiency improvements, combined with saturation of demand for services such as heating and hot water.
Demand side (DJ-DS) – technical energy efficiency improvements to the pre- and post-1996 housing stock, also some accelerated demolition of old housing.
Integrated scenario (DJ-IS) – as for the Demand Side scenario, but also including energy supply side changes which result in electricity with lower carbon intensity (thus the demand side and integrated scenarios have the same final energy use but different carbon emissions).

Each scenario comprises annual information relating to each 'notional' dwelling, such as U-values and seasonal space and hot water heating efficiencies. The data are input into the BREDEM-based energy and CO_2 emission model. This is primarily demand side oriented, but it also includes a very simple supply side model. The supply side model consists simply of assumed future values for the carbon intensity of electricity, based on possible generating fuel mixes up to 2050. The BREDEM-based model then utilises this information to calculate the delivered energy use and CO_2 emissions attributable to each 'notional' dwelling, for the particular year in question. This process is undertaken for the years 1996 to 2050 inclusive. Finally, information on the total number of 'notional' dwellings in each year is then used to scale the delivered energy use and CO_2 emissions up to the level of the whole UK housing stock.

Johnston introduced minor variations from the BREDEM 9.60 methodology, the most notable of which are:

- A single- rather than two-zone heating approach (discussed in further in Section 4.6.8);
- Heating and hot water systems are assumed to be fuelled by either gas or electricity. There is no provision for oil, solid fuel or other sources of energy;
- Hot water requirement calculation is based on number of people per household rather than on the floor area of the property.

The first two variations were introduced in order to simplify the modelling process and reduce the input information requirements. Changing the method for calculating hot water demand was felt by Johnston to offer a more realistic representation of hot water use than the BREDEM method.

By simplifying the fuels in the model to gas and electricity, Johnston focused on the two major fuels for heating and hot water, the next most important is heating oil, followed by solid fuel, which is still losing market share. In 1996, gas and electricity together accounted for 86.4% of household final energy use, by 2002 this had increased to 88.1% (DTI 2003a). Johnston increased the percentage of space and water heating supplied by electricity and gas. For example, central space heating was modelled as 80% gas and 20% electricity in 1996. Despite this simplification, the carbon emissions from Johnston's model for 1996 matched those reported by the government. The emissions per kWh of the fuels not modelled (oil and solid fuels) are in-between those of gas and electricity, so a mixture of gas and electricity is a good substitute for the other fuels in carbon terms.

One of the key challenges of Johnston's research was to find suitable values for the characteristics of his notional dwellings. Figures for the average size of windows, orientation of houses and ventilation characteristics, for example, are not easily come by. Combining such data as were available, along with his own best estimates where data were missing, in a model to get values which match the measured energy consumption of the housing stock was a considerable achievement.

Johnston validated the model by comparing its results with published data from BRE (Shorrock & Walters 1998) and actual stock energy consumption data for 1996. The BAU projection from the model was also compared with the 'reference case' projection developed using the BRE's BREHOMES model (Shorrock et al. 2001).

4.3.2 Results

Compared to emissions of carbon dioxide in 1990 the following emission reductions were projected to occur by 2050:

- a 37% reduction under the business as usual scenario (DJ-BAU) by assuming a continuation of current trends in fabric and end-use efficiency measures and the carbon intensity of electricity generation, e.g. ownership of condensing boilers rising gradually to 76% of the stock by 2050, a steady improvement in the U-values of all building elements;
- a 61% reduction under the demand side scenario (DJ-DS), by applying additional demand side measures to the business as usual scenario, e.g. all solid walls are insulated by 2050, solar water heating is installed for all new houses after 2010 (see Section 4.7 for full details);
- a 67% reduction under the integrated scenario (DJ-IS), by applying a number of electricity generation measures to the energy supply side of the demand side scenario;

- a reduction in excess of 80% is technically feasible given existing technology, if a significant proportion of gas-fired space heating systems are replaced by electrically-driven heat pumps. However, this represents a strategic shift in the application of both demand side and supply side technologies.

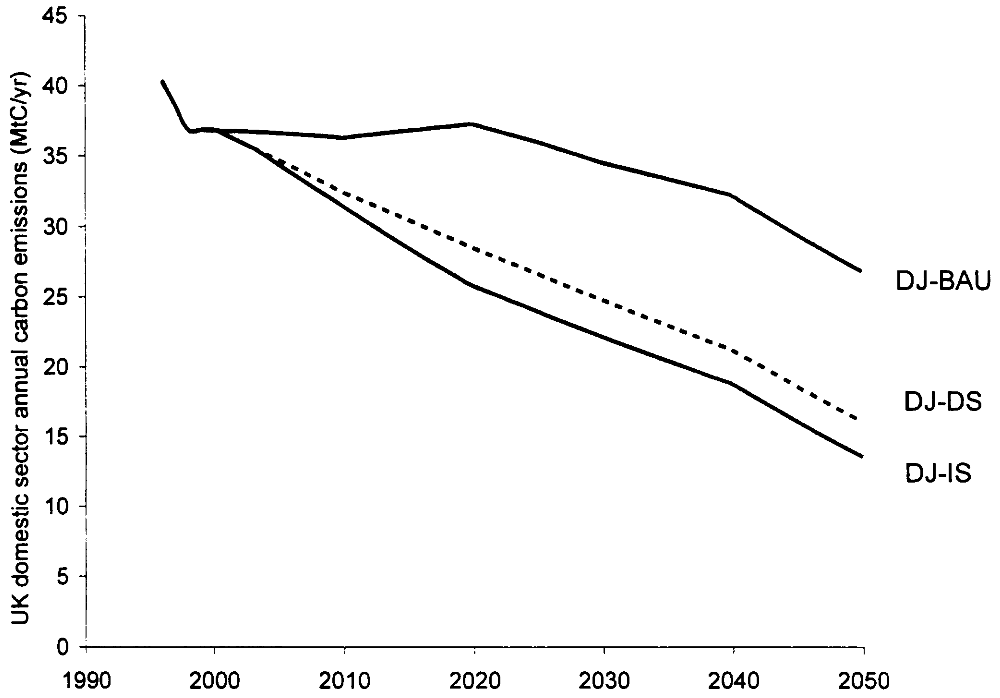

Figure 4.2: Projected annual carbon emissions UK domestic sector, Johnston's scenarios, 1996-2050

As Johnston states, his work has demonstrated that: "*by the middle of this century it is technically possible, using currently available technology, to achieve the sorts of reduction in the CO_2 emissions of the UK housing stock that are likely to be required to stabilise the atmospheric CO_2 concentration and mitigate the effects of climate change*" (2003a:180). However, he also concludes that: "*There appear to be no easy, trouble-free technological options for the UK housing stock*" (2003a:180).

4.3.3 Discussion

Johnston's model has a considerable number of strengths:

- details of its construction and the data and projections used are publicly available and clearly explained;
- it is based on a calculation method which is widely accepted and used in the UK;
- it is relatively straightforward to replicate;
- it has proven to be useful for investigating scenarios over the next fifty years.

In addition, there are currently no alternative models documented and available in the public domain.

However, there are also a number of limitations of the model:

- it contains only two types of housing, so it is not possible to investigate scenarios specific to particular construction types other than by assuming an impact on the average heat transfer of properties;
- supply side modelling is relatively crude;
- in common with other physically-based, bottom-up models, the likely effect of various economic variables, such as fuel prices, are not estimated.

There are also the limitations inherent in the idea of using any model to project forward 50 years. Even in a model such as this, where good historic data is available to inform the projections, uncertainty increases significantly over time. This uncertainty is attached to the assumptions and projections rather than the calculations. However, inspired by the requirement to make carbon savings over the long term, a considerable number of organisations are using modelling to look forward fifty years, as discussed in Chapter 3. Although fifty year projections have to be used with caution, there is evidently agreement that they have a valuable role in helping to think about the future.

It has been decided to replicate Johnston's model and use it for this thesis research because its advantages significantly outweigh any disadvantages.

4.4 Analysis of Johnston's projections

When Johnston's projections are considered in comparison with the historic record of energy use since 1970 it becomes apparent that his BAU scenario is conservative in terms of the expected development of energy use (Figure 4.3). Both the BAU and Demand Side scenarios show decreasing energy consumption from 2000 onwards. The projections for both scenarios decrease more rapidly from 2040 for a number of reasons: the internal temperature stops rising and stabilises at 21 °C for pre-1996 dwellings, which form the majority of the stock; household numbers fall slightly; and the rate of demolition of older, more energy consuming properties is accelerated.

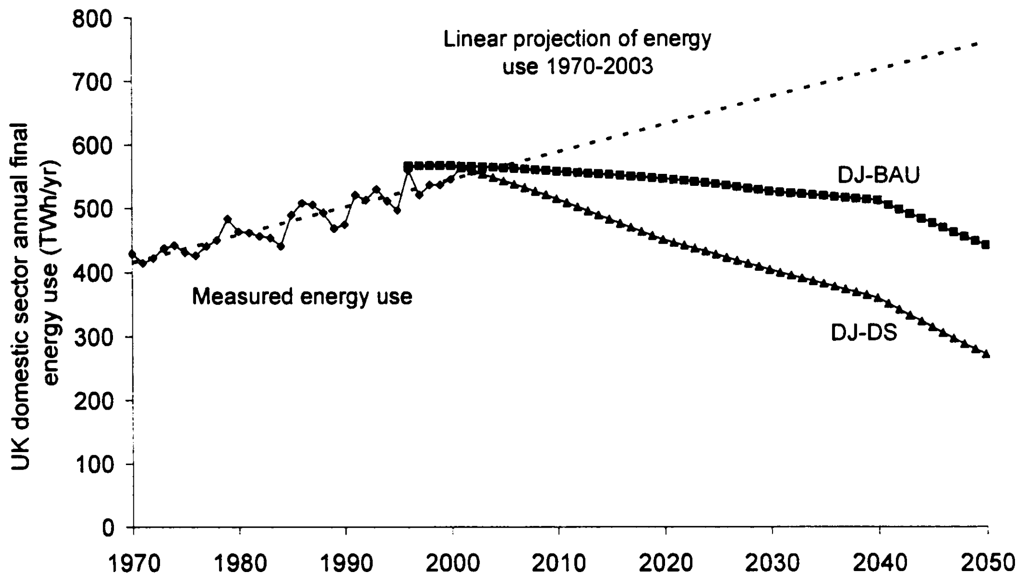

Figure 4.3: Actual and projected annual final energy use, UK domestic sector, 1970-2050

Sources: Johnston 2003a, DTI 2004a

Both past trends and current circumstances suggest energy consumption could increase considerably more than in the BAU scenario. As Chapter 3 demonstrated, historical evidence shows that it is very easy to underestimate increases in future energy demand. A simplistic linear projection of final energy use trends 1970-2003 (shown in Figure 4.3) to 2050 results in energy consumption increasing by 40% from 2000 levels. This contrasts with Johnston's BAU projection of a 22% reduction by 2050. There is considerable risk that Johnston's estimates of future energy use (and those of BRE to 2020 which are similar (Shorrock et al. 2001)) will be exceeded by a significant margin. The key factors which could lead to increased use of energy are considered in more detail in later parts of the chapter.

Because Johnston's projections date from 1996, it is possible now to compare them with official government figures for household energy in the years following Johnston's work (Figure 4.4), and to take account of the effect of external temperature on actual energy use figures. The external temperature data here are for Great Britain, and is the average temperature over the six coldest months of the year (January – April, November and December) (calculated from data in DTI 2004a).

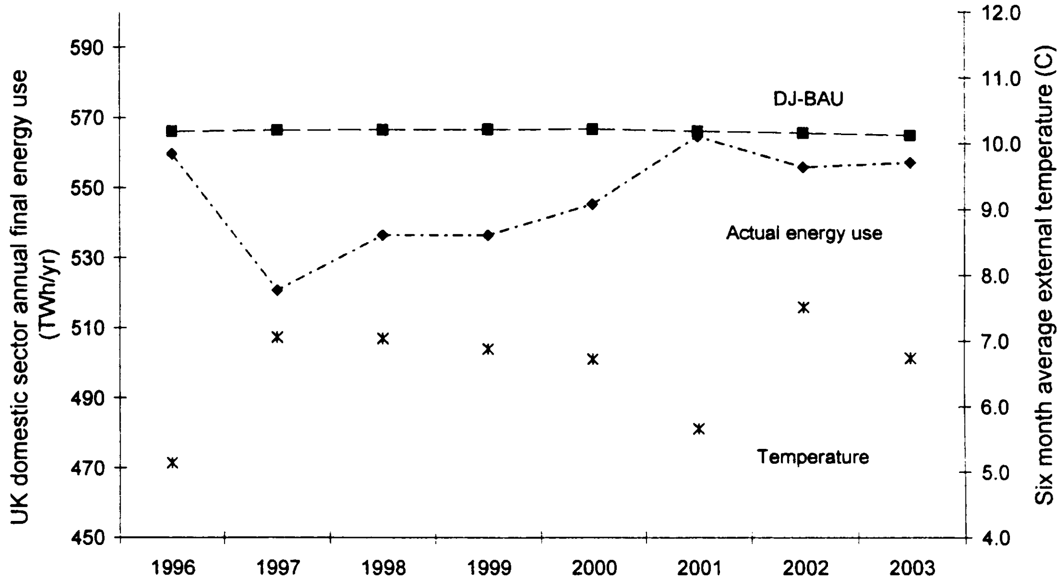

Figure 4.4: Comparison of DJ-BAU projections, actual energy use and external temperature, 1996-2003, UK domestic sector

Sources: Johnston 2003a, DTI 2004a

A comparison of Johnston's model projections with DTI actual energy use data suggests that there may be systematic differences between the model outputs and actual energy use. The model over-estimates energy consumption 1997-2000 (none of which were cold years, unlike 1996). More importantly, the data show an upward trend in energy consumption in real life whereas the model indicates steady energy consumption.

Johnston's model could be validated further by comparing its estimates of energy consumption in years prior to 1996 with actual data. However, this would involve a considerable amount of additional work and is not a priority for this research.

4.5 Replicating Johnston's model

Based on the description and data in Johnston's thesis, a version of his model was created – identified as 'TF model'. TF model was created in Microsoft Excel. The BREDEM-based calculations on which TF model is based are described in Appendix 2. Johnston's thesis contained a clear description of the data inputs to the model, and tables of inputs and outputs were provided. However, given space constraints not every input figure could be included, and therefore some assumptions and interpolations have had to be employed based on interpretation of the thesis text. As a result, TF model contains some numbers which are likely to be slightly different from Johnston's ('DJ model').

The electricity consumption for cooking and lights and appliances is modelled in a very simple way, and so there were no problems in exactly replicating Johnston's results. However, the modelling of space and water heating is much more complex, and the results from TF model do not match Johnston's precisely. The comparisons for space and water heating for DJ-BAU are shown below.

Table 4.1: Comparison between TF and DJ model outputs, business as usual projection

	Space heating (TWh/yr)			Water heating (TWh/yr)		
	TF model	**DJ model**	**Difference (%)**	**TF model**	**DJ model**	**Difference (%)**
1996	349	341	2.3	134	133	-0.5
2000	351	341	3	131	131	0.1
2010	344	340	1.2	123	124	1
2020	336	336	-0.2	113	114	0.6
2030	323	326	-0.8	103	104	1
2040	315	313	0.6	95	97	1.3
2050	258	253	1.8	87	88	1

Space heating

The TF space heating figures vary from Johnston's by up to 3%. The difference is not systematic, which indicates that it is unlikely to be caused by a simple error in the author's modelling. Johnston was of the opinion that this level of difference from his results could be explained by small differences in input values (Johnston 2003b).

Water heating

The TF water heating energy consumption figures are similar to Johnston's, and vary by a maximum of 1.3%. Again, the most likely explanation for the difference is the small difference in input values. However, this coincidence of values was achieved by including primary circuit losses for electric water heating as well as for gas water heating – and according to SAP Table 3 (BRE & DETR 1998) there should be no such losses for electric water heating. This is because primary circuit losses are those which occur between the boiler and the storage tank, and which are not relevant for electric systems where the energy source is in the tank and there is no primary circuit. If primary circuit losses are excluded for electric water heating, the energy required for water heating is lower than calculated in Johnston's thesis. However, according to SAP this is the correct calculation and it appears that Johnston made a mistake in his model.

When losses from primary circuits for electric storage water systems are excluded, the total amount of energy needed for water heating decreases (Table 4.2). The difference between the two calculations decreases over time because primary circuit losses are expected to decrease considerably over time as boiler systems are replaced by those which include better controls and insulation and thus have lower primary circuit losses.

Table 4.2: Comparison between different methods of calculating water heating energy use, business as usual scenario

	DJ model (TWh/yr)	TF model adjusted to exclude primary circuit losses for electric systems (TWh/yr)	Difference (%)
1996	133	125	6.4
2000	131	123	6.3
2010	124	117	5.7
2020	114	109	4
2030	104	100	3.3
2040	97	94	2.9
2050	88	86	1.8

This was the only instance where it appears that Johnston's model deviated from the procedure described for SAP (other than deliberately). No other errors were found or fixed. All subsequent data produced by the TF model excludes primary circuit losses for electric systems.

Having successfully replicated Johnston's model, the following sections use the author's version of the model to investigate a number of different issues. Note that where figures are quoted from Johnston's thesis they are his original numbers, not the slightly different ones generated from TF model.

4.6 Variations to data inputs to Business as Usual scenario

4.6.1 Introduction

New information has become available since Johnston completed his modelling, and here key new data which could change the outcome of the business as usual scenario are identified. The effect of including this new data on the BAU projection, together with the alteration to water modelling identified earlier, is calculated. The combined effect of error fixing and new data is illustrated in a 'TF-BAU' scenario. However, other aspects of DJ-BAU, e.g. rates of adoption of more efficient equipment and insulation measures, changes in usage patterns, have not been reconsidered. Instead, after the effects of new data have been explored, emphasis is placed on looking at a range of future possibilities (Section 4.8).

4.6.2 Household numbers

In Johnston's model, household numbers were based on 1998-based population projections. Since then there have been a number of revisions to population projections, the latest of which is based on 2002-based projections. The 2002-based projection from the Government Actuary's Department (GAD) is the one which will be used in this thesis. The next revision to population projections is not due out until October 2005 (Shaw 2004).

The GAD population projections can be combined with existing household size projections to give a new set of household number projections. There is little difference between the 1998-based and 2002-based projections until 2020. However after this point the difference between the two increases, such that the 2002-based household figures are 1.4% higher in 2030, 2.8% higher in 2040 and 3.9% higher in 2050 than the 1998-based projections. The increases arise primarily because of higher life expectancy assumptions, but also as a result of differences in the base population used for the projections, and higher expectations of the number of future immigrants (Shaw 2004). Using the 2002-based population projections in the model leads to an increase in energy consumption of 1.5% in 2040 and 2.3% by 2050.

4.6.3 Internal temperature

In Johnston's BAU scenario, temperatures in the pre-1996 and post-1996 dwelling are assumed to rise to 21.0°C and then remain the same. This temperature is reached by 2040 in the pre-1996 dwellings and earlier, by 2020, in the post-1996 dwellings. Saturation of internal temperatures in 2040 leads to a more dramatic reduction of energy use (space heating) from that point forward. The temperature figures are 24-hour averages for the whole house and the whole heating season.

Table 4.3: Mean internal temperature (°C) of the notional dwellings under all scenarios in Johnston's model

	1997	2000	2010	2020	2030	2040	2050
pre-1996 dwelling	16.1	16.5	17.6	18.7	19.9	21.0	21.0
post-1996 dwelling	18.0	18.4	19.7	21.0	21.0	21.0	21.0

Historic evidence for changing internal temperatures shows clearly that there is good reason to expect them to continue to increase over time (Figure 4.5). The increase over time is clear, with annual variations affected by external temperature. In colder weather lower internal temperatures are achieved.

Figure 4.5 shows two different types of internal temperature data, monitored and estimated data. The monitored data can be split into two groups:

- Nationally representative data (DoE 1991b, DoE 1996, DETR 2000d, Hunt & Gidman 1982), these are shown as solid coloured points.
- A wide variety of data from smaller monitoring exercises, most of which were collated by Lowe, Chapman, & Everett (1985).

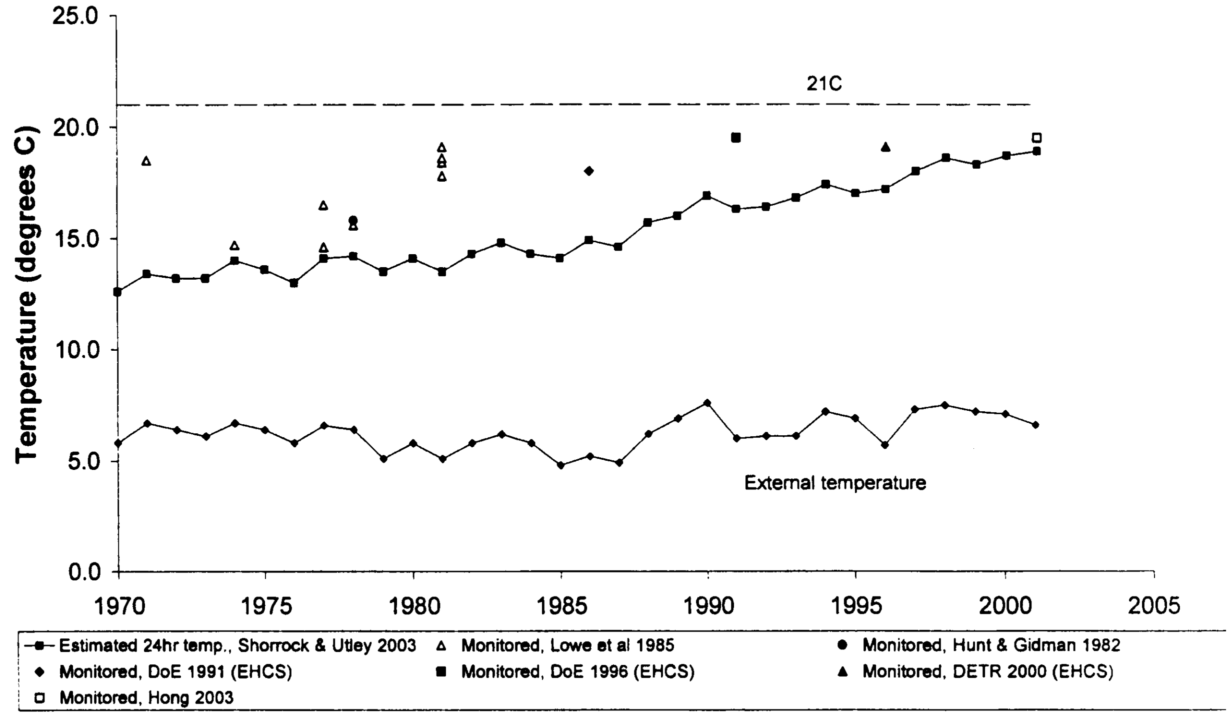

Figure 4.5: Internal temperature monitored (in living rooms) and estimated, and external winter temperature, 1970-2001

All of the monitored data except Hong (2003) is based on spot measurements of temperature in the living room at one point in time, whereas the estimated data relates to whole house 24 hour average temperatures. Spot temperatures could be expected to be higher than 24hr averages as they are normally taken during the time the heating system is on (the precise relationship between spot temperature and 24hr temperature depends on the time of day the reading was taken, thermal characteristics of the house as well as the heating pattern employed by the householders).

The estimated data represent 24-hour average values for the whole property. These values are calculated by BRE from their BREHOMES model, by adjusting internal temperature such that the model outputs match to measured energy use figures for the whole domestic sector supplied by DTI (Shorrock & Utley 2003). This procedure will result in inaccurate temperature estimates if there are systematic errors in the model. For example, if the air leakage rates from properties (which are very variable, and not well characterised) are underestimated, then more energy will be lost through this route than the BRE model assumes, and the estimated internal temperatures will be higher than those achieved in reality. BRE themselves advise that the changes in internal temperatures over time are more accurate than the absolute value of the temperatures (Shorrock & Utley 2003).

The English House Condition Survey (EHCS) temperature data is also available for halls as follows: 1986 – 16.3°C, 1991 – 18.3°C, 1996 – 17.9°C (DoE 1991b, DoE 1996, DETR 2000d). The Warm Front data also included bedroom temperatures at 18.3°C (Hong 2003). These temperatures are 1.2-1.7°C lower than those measured in living rooms. For clarity they have not been included in Figure 4.5.

Evidence subsequent to Johnston's thesis shows that household temperatures have risen more quickly than he anticipated. Estimates of internal temperatures from BRE suggest that in 2001 the 24-hour average temperature was 18.9°C (Shorrock & Utley 2003), which exceeds Johnston's projections for 2010. In addition, spot temperature measurements in English halls in 1996 reached an average of 17.9°C (DETR 2000d). Hall temperatures are thought to be representative of whole house temperatures, for spot temperature readings (Hunt & Gidman 1982). Also, 24 hour monitoring data from a limited number of low income households in 2001 showed average temperatures of 19.5°C in the living room and 18.3°C in the bedroom (Hong 2003). Thus, based on this new information, the temperature projections in the TF-BAU have been adjusted as shown in Table 4.2.

Table 4.4: Mean internal temperature (°C) in TF-BAU

	1997	2000	2010	2020 - 2050
pre-1996 dwelling	16.1	16.5	19.5	21
post-1996 dwelling	18.0	18.4	21	21

Temperature values from 1996 to 2000 are identical to Johnston's, but after that progress towards a universal average of 21°C is accelerated with post-1996 dwellings reaching 21°C by 2010 and pre-1996 dwellings reaching that temperature by 2020. Successive English House Condition Surveys showed an increase of 1.6°C in hall temperatures in the ten years between 1986 and 1996 (these years had similar external temperatures). So the data shows that changes of at least one and a half degrees are possible in a decade. This is just one projection of many that could be made, but it fits better with the new temperature data available than does Johnston's more conservative original (alternative future temperature scenarios are explored further in Section 4.8). This change in temperature projections leads to an increase in energy consumption of almost 30% in 2010 and 2020, which drops to 12% by 2030 and to zero by 2040, by which time the temperatures in the two scenarios are equal.

Internal temperature plays a crucial part in fine tuning the outputs of both Johnston's and BRE's models. Temperature is used to ensure that modelled energy consumption matches actual totals. In the case of post-96 dwellings, Johnston adjusted the internal temperature so that energy consumption was in agreement with the theoretical space heating energy consumption of a dwelling built to the 1995 Building Regulations standard.

4.6.4 Floor area of dwellings

New data from EHCS in 2001 (ODPM 2003) suggest that the estimate of floor area for new dwellings reported in EHCS 1996 (DETR 2000d), and used by Johnston, was an underestimate. Their new figure for post-1980 dwellings is $83m^2$ as opposed to $76m^2$ reported in 1996 (Table 4.5). The EHCS 2001 report does not offer any explanation for the difference between the most recent and previously reported figure. Researchers responsible for the EHCS were unable to explain this discrepancy, which they describe as 'an aberrant result', stating that there had been no change in the surveying methodology and that other factors did not seem sufficient to explain the change (McIntyre 2004). The figures can both be right only if the average floor area of dwellings built between 1996 and 2001 was considerably greater than those built 1980-1995, at $104m^2$.

Table 4.5: Estimated floor areas of the English housing stock, 1996 and 2001 data

Data source	National average floor area (m^2)	Pre-1980 average floor area (m^2)	Post-1980 average floor area (m^2)
1996 EHCS, (DETR 2000c)	85	-	76
2001 EHCS (ODPM 2003)	87	88	83

Johnston projects pre-96 dwelling to reduce by $5m^2$ from 1996 to 2050 as older, larger dwellings are gradually demolished. In contrast the average useable floor area of the post-96 dwelling is assumed to remain constant (with increases in detached dwellings being offset by increased building of flats in response to government policy on higher densities). If new values from the 2001 EHCS are substituted for Johnston's, with the same trends after 2001, this results in a 3.7-3.9% increase in annual space heating energy use over the period 2010-2050.

4.6.5 Proposed revisions to building regulations, July 2004

As a result of targets set in the Energy White Paper (DTI 2003b) revisions to the energy efficiency component of building regulations (Part L) are to be brought forward from 2008 to 2005. The currently proposed indicative targets[1] for 2005 and 2010, which may be altered after the consultation period, are shown below (Table 4.6).

[1] The 2005 Part L building regulations will require achievement of a target carbon emissions rate per square metre (TCER). Standards are no longer specified in terms of U-values, however if these values are achieved, the building should meet the TCER.

Table 4.6: Possible future building regulation standards for new housing

Standard	Component / house type	Building regulations 2002	Potential indicative targets for 2005	Potential indicative targets for 2010	Johnston's values for 2009	Johnston's values for 2025
Indicative standards for fabric insulation (W/m^2K)	Roofs	0.16-0.25	0.13	0.10	0.16	0.10
	External walls	0.35	0.27	0.20	0.25	0.15
	Ground floors	0.25	0.22	0.20	0.22	0.10
	Average of all windows, doors and rooflights	2.0-2.2	1.80	1.40	1.80	1.00
Airtightness standard (Permeability in $m^3/h/m^2$ at 50 Pa)		10	7	5	10	1

Source: Adapted from Johnston 2003a, ODPM 2004, ODPM 2001

The standards which Johnston used in DJ-BAU for 2002 are basically the same as those introduced by the 2002 building regulations. However, the current proposals for future building regulations in 2010 are more ambitious than those in the DJ-BAU scenarios for 2009, which are similar to those proposed for 2005. Building standards may be rising faster than Johnston expected. However, judgement on this must be reserved until the standards for 2005 are finalised.

If the potential standards for 2005 and 2010 are used to replace Johnston's values from 2002 onwards the actual reduction in energy consumption is not particularly great. Running the numbers through the model shows that the annual energy saving compared with Johnston's scenario is less than 0.5%, with the greatest savings occurring around 2020 and decreasing to 2050 as the U values converge.

As Chapter 2 noted, the 2002 amendment to Part L paid much more attention than previously to work in existing buildings by setting standards for replacement windows and boilers. With the proposals for further amendment in 2005, that trend has been continued with a suggestion that where the cost of building work on existing dwellings exceeds £8,000, opportunities should be taken to improve the energy efficiency of the dwelling. It is also proposed that most new and replacement boilers will have to be condensing, which, all other things being equal, would lead to lower energy use than in DJ-BAU. However, there is still debate about the timetable for achieving this requirement, with the government apparently not expecting condensing boilers to capture the whole new boiler market until 2009 (ENDS 2004b). The effect of these possible changes has not been modelled in this thesis.

4.6.6 Effects of these changes on the BAU projection

The changes that have been identified, population, floor area, internal temperature and U values, plus the correction to the hot water calculation can be combined to give a TF-BAU scenario, see Figure 4.6. Not surprisingly, the change to internal temperatures dominates the effect on energy use. There is a much greater use of energy particularly in the period 2002-2020, after which the difference declines. By 2040, when both scenarios have the same internal temperatures, the remaining small difference (of around 3.5%) is due to the increased population, floor area and the revised hot water calculation included in TF-BAU. Although the difference between DJ-BAU and TF-BAU is small in 2050, over the period 1996-2050 TF-BAU results in an increase in cumulative energy consumption of 10%.

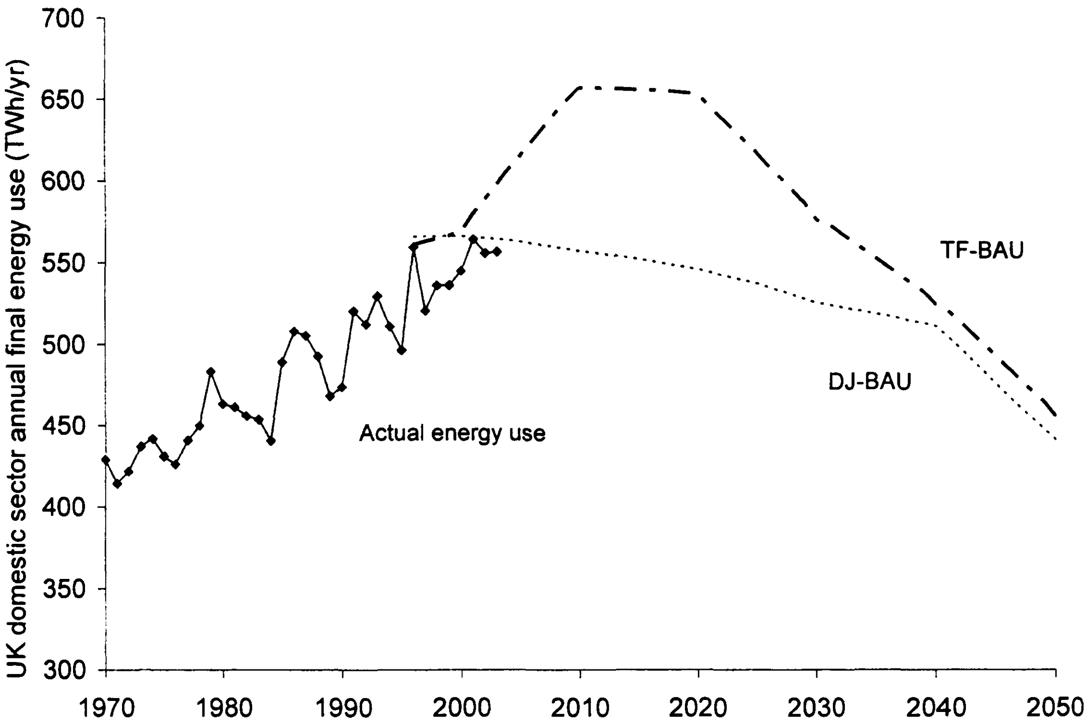

Figure 4.6: Comparison of DJ-BAU and TF-BAU 1996-2050 and actual energy consumption 1970-2003, UK domestic sector

Source: DTI 2004a

Compared with the historic record of energy consumption 1970-2003, TF-BAU seems to have a somewhat high rate of increase up to 2010. The point of creating TF-BAU is not to suggest that it is an accurate projection of future energy consumption, but more to demonstrate how different Johnston's projections could have been, given the new data now available. Of all the alterations, the key one is the internal temperature.

4.6.7 New data not included in the model

There are other input factors for which new data has become available, or where Johnston's approach could be questioned, but these have not been included in TF-BAU, for reasons explained below.

Types of water heating systems

In DJ-BAU, ownership of storage hot water systems in pre-1996 households remains constant at around 77% between 1996 and 2050. In the post-1996 housing stock, ownership is expected to fall from 83% in 1997 to 76% in 2050. However, half of new boilers are 'combis', that is there is a second heat exchanger in the boiler which works as an instantaneous water heater (Brinkley 2002). So Johnston's figures overestimate the extent to which storage systems are likely to continue to dominate water heating.

To investigate what difference a switch away from storage to instantaneous water heating would make to energy consumption, the proportion of each type of system was varied in the TF model. The proportion of instantaneous gas water heating was increased to 50% by 2030 for pre-1996 systems (to allow replacement of the current stock) and to 50% for post-1996 stock from 2002 onwards. These changes resulted in a reduction in water heating energy use of 6-12% depending on the year. The difference is due to the variation in losses and efficiencies assumed between the different systems. However, because very little is known about how people use different types of water heating systems, whether these figures reflect what might actually happen is uncertain. For this reason, although there is a case for changing the TF-BAU case, it will actually be left as it is in Johnston's model. Demand for hot water is discussed in greater detail in Section 4.7.1.

New version of SAP

Since Johnston developed his model, a new version of the government's Standard Assessment Procedure for the energy rating of dwellings has been published (BRE 2001) and a 2005 version is out for consultation (ODPM 2004). The new 2001 version of SAP is version 9.70, Johnston's model was based on version 9.60 (BRE & DETR 1998). The key changes were to introduce a Carbon Index (which is a number between 0 and 10 based on the carbon dioxide emissions per square metre associated with space and water heating, the higher the number the better the performance) and to raise the upper limit of the SAP scale from 100 to 120. These changes, and the other changes introduced, do not affect the calculations of energy consumption in Johnston's model. Thus, the introduction of a new version of SAP does not require changes to the model and so the TF model is based on SAP version 9.60.

Heating degree days, SAP and climate change

Johnston has made allowances for future changes in climate, using data supplied by the UK Climate Impacts Programme (Hulme, Turnpenny, & Jenkins 2002). Johnston used the UKCIP02 Medium-High emissions scenario, in which the average temperature rise is 1.87°C by 2050. However, this average annual temperature change does not apply equally across the UK or throughout the year. There is a different temperature change predicted for spring, summer, autumn and winter. Summer sees the highest temperature rises. The pattern also varies within the country with the south east heating up the most, and the north west the least. The most useful figure for the model would be population density-weighted heating season temperature change. The average temperature rise during the heating system is likely to be lower than the annual average rise. However, as population density is highest in the south east, which will experience the greatest temperature rises, the average temperature rise experienced by households is likely to be higher than the geographical average temperature rise. UKCIP do not publish temperature figures in population-weighted format and it has been decided not to pursue this analysis further at this time.

Air change rate

In Johnston's model, the mean air leakage rate is based on research carried out by BRE which monitored the air leakage of several hundred dwellings. In DJ-BAU for pre-1996 buildings a very small reduction in the mean air leakage rate is expected to occur as a number of the existing dwellings undergo post-construction airtightness work, but apart from this it does not change to 2050. However, over the period to 2050, the rate of cavity fill and double glazing increases considerably in pre-1996 dwellings, and this would be expected to lead to lower air change rates - so should the air change rate in the model be changed over time?

Recent research has indicated that changes to air infiltration rates in buildings can be more complex than expected. Under the English Warm Front programme (outlined in Chapter 2), dwellings were draught-proofed, and cavity wall insulation was installed, which was expected based on modelling to reduce the air change rate. However, tests before and after intervention showed this was not the case. The explanation is that at the same time, central heating was installed, which involved breaching the building envelope (e.g. holes in floors for pipework) and creating more opportunities for air infiltration (Hong et al. 2004). Thus, although the changes identified above might be expected to reduce the air infiltration rate more than Johnston expected, the data on the effect of changes to the building fabric on air infiltration are not good enough to be confident that the model should be changed.

4.6.8 Making structural changes to the model

In theory it would possible to make changes to the structure of the model, to extend its capabilities. One possible change would be to include more ages or types of housing. There is some data available from the English House Condition Surveys about the physical characteristics of English housing based on age and type. Adding a greater variety of dwelling types would, for example, allow better analysis of the effects of increasing demolition rates, and demolition could be targeted on the worst housing rather than the average. Increasing the number of dwelling types would also allow a better focus on particular refurbishment methods, particularly wall insulation, which depend on the types of housing. It would not, however, add to our understanding of saving possibilities for hot water and electricity use for lights and appliances, because there is no evidence linking either of these with housing age or type. However, as Johnston concluded, adding more ages or types of housing would considerably increase the amount of data required. Given the aims of this thesis, this development of the model is not a priority. In addition, this research is being undertaken elsewhere (Boardman 2003).

Another possible change would be to re-introduce two zone heating as this would make it easier to investigate scenarios where heating is concentrated on living areas. In Johnston's model temperature is modelled as an average for the whole house over 24 hours. However, having just one zone for heating fits well with trends in whole house heating. The evidence is that although differences remain between living areas and the temperature in other areas of the house they are rather small. The latest EHCS data showed a 1.2°C difference between living room and hall temperatures in 1996 (DETR 2000d) and preliminary data from the Warm Front project also showed a 1.2°C difference between bedrooms and living room temperatures in 2001 (Hong 2003). In addition, it is easy to reduce the whole house temperature a little to simulate cooler non-living room areas. So, re-introducing two zone heating is not a priority.

In summary, it has been decided not to make any major changes to the structure of Johnston's model. The change which might be most useful, that of adding additional housing types, would involve a considerable amount of extra research, time it was felt was better spent pursuing other aspects of research.

4.7 Johnston's technological savings future – DJ-DS

4.7.1 Introduction

Johnston's Demand Side scenario (DJ-DS), as illustrated in Figure 4.3, introduces a wide range of technological improvements on the demand side which, together with the underlying downward trend in energy consumption, are sufficient to result in a reduction of 58% in carbon dioxide emissions compared with 1996. Johnston provided a comprehensive summary of technical options for saving energy and carbon from the UK housing stock. The work particularly concentrated on bringing together evidence on saving energy from space and water heating. The technological improvements included in DJ-DS are based largely on technologies which have been used in advanced housing or demonstration projects, and their energy saving benefits have been measured and proven.

4.7.2 Johnston's key technologies

Johnston identified many technological improvements which together would lead to the carbon and energy savings in his DJ-DS scenario. The key technologies and the years of their adoption for both pre- and post-1996 housing are described in Table 4.7. For post-1996 housing, the ultimately achievable standards are projected to be met by 2010. Tables showing the U-values for elements of construction in pre- and post-96 housing are included in Appendix 3.

Table 4.7 Key technologies in DJ-DS and their uptake in pre- and post-1996 housing

Technology	**Pre-1996 housing**	**Post-1996 housing**
Solid wall insulation	All uninsulated solid walls to have 150mm of insulation by 2050.	By 2010 wall insulation standard to meet very high standard, requiring either extra wide filled cavities or highly insulated solid walls.
Cavity wall insulation	All cavity walls to be fully filled by 2050.	
Loft insulation	All accessible lofts to have insulation topped-up to 200mm. Roofs with inaccessible lofts also insulated.	All to reach very high standard by 2010.
Windows and doors	All replaced by 2050 – to the relevant standards at time of replacement.	By 2010 meeting standards will require high specification triple glazing.
Air tightness	30% of stock to undergo post-construction airtightness work by 2050. This leads to a change in average dwelling from 13.1ac/h @ 50 Pa to 11ach/h @ 50Pa in 2050	Average new home built almost as air tight in 1997 as average pre-96 in 2050, at 11.7 ac/h @ 50 Pa. Standards improve considerably over time, giving average of 3.5 ac/h @ 50Pa by 2050.
Condensing gas boilers in gas heated properties	100% by 2050, except for CHP households	By 2010 many houses will be built that require no space heating. The remaining houses will use condensing gas fires (full central heating not required) or electric heat pumps.
Heat pumps for electrically-heated properties	100% by 2050	
Combined heat and power	5% by 2050	
Solar water heating	10% by 2050	100% by 2010
More efficient lights and appliances	Electricity consumption per household falls to just over half 1996 value by 2020 and remains steady after that.	
Cooking energy use	Falls by about one quarter per household from 1996 value by 2020 and remains steady after that.	

The other key DJ-DS assumption is that the demolition rate of housing is twice that in DJ-BAU, increasing the proportion of the stock that is made up of post-1996 housing.

As a result of all these improvements (and combined with increasing household numbers), final energy use by end use in the UK domestic sector in 2050 is reduced by the following amounts in DJ-DS compared with 1996:

- Space heating: -57%
- Water heating: -51%
- Lights and appliances: -30%
- Cooking: no change

This gives a total reduction in final energy use of 50%. Combined with some fuel switching towards gas from electricity, the decreasing carbon intensity of electricity, and use of solar water heating, this leads to a reduction in carbon dioxide emissions from 1996 of 58.4%.

4.7.3 The barriers to achieving savings from technology improvements

General arguments have already been made in Chapter 3 about the optimistic assumptions which tend to be used in energy efficiency modelling with regard to take up rates, the efficiency savings of particular technologies and how they may actually be used in practice. This section focuses on three of the technologies identified in Table 4.7, solid wall insulation, new heating systems and solar water heating, and identifies where assumptions about their efficiency and take up may be optimistic. Behavioural factors are discussed in Section 4.8. Johnston himself observed that there were no 'trouble-free' routes to making energy savings - this section illustrates what a few of those troubles may turn out to be.

Solid wall insulation

External insulation for pre-1996 solid walled properties is a key energy saving technology in DJ-DS. By 2050 Johnston assumed that all uninsulated solid walls will be thermally upgraded by adding 150mm of insulation. At this level of insulation, solid walls would be more highly insulated than filled cavity walls. Developing cost-effective insulation for solid walls has been identified as a key area requiring more research, development and demonstration work (DEFRA 2004b). Assuming sufficient insulation can be added to most walls at reasonable cost, two key problems with achieving such a high uptake of external insulation can be identified: creating a market and overcoming aesthetic objections.

Achieving a market for installing external solid wall insulation for private householders, and persuading people to pay for it is likely to be very challenging. In the social housing sector, there is experience of successfully installing solid wall insulation usually in cases where the building fabric also needs upgrading or there are problems with water penetration so that the insulation has multiple benefits. However, there is currently no market for solid wall insulation for private householders and it can be very difficult even to get quotes for having this type of work done for a single dwelling (Simmonds 2004). Cavity wall insulation is considerably easier and cheaper to install than solid wall insulation (Shorrock, Henderson, Utley, & Walters 2001). By 2001 32% of cavity wall properties had been insulated, a rise from 2.4% in 1974 (Shorrock & Utley 2003). There is effectively no market, in that almost all cavity insulation installations are subsidised either by energy companies or government. This does not bode well for solid wall insulation.

The aesthetics of adding insulation and rendering to the outside of many brick- and stone-fronted properties is likely to prove controversial, and would be restricted by current law for listed dwellings and those in conservation areas. There are about half a million listed dwellings in Great Britain, and before altering their appearance consent has to obtained from the local planning authority. In addition, it is unlikely that alterations would be permitted to homes in conservation areas if the alterations detract from the appearance or character of the area (Highfield 2000). There is no official estimate of the number of dwellings in conservation areas in the UK. However, there were more than 8,000 conservation areas in England in 2002, and it has been estimated that around 5% of the stock is of historic interest (Oreszczyn 2004a). In addition, brick is the traditional external finish in many areas of the UK, so that a switch to render might well be resisted. The millions of houses whose external appearance cannot currently be changed poses a challenge to universal solid wall insulation.

Thus, for economic / market and aesthetic reasons the assumption that solid wall insulation can be added to all pre-1996 solid wall properties is very optimistic.

Condensing boilers, CHP and heat pumps

Johnston identified three key technologies for improving the efficiency with which space and water heating is delivered: condensing gas boilers, CHP and heat pumps. The recent proposed changes to building regulations from 2005 (ODPM 2004) suggest that condensing boilers will make up most of the market for new and replacement boilers within the next few years. Thus Johnston's DJ-DS projections may well be exceeded in terms of rate of adoption of condensing boilers.

CHP/district heating has been much more popular in some other EU countries than in the UK with over half of Danish households connected in 2000 (Griffin & Fawcett 2000) compared with only around 2% of UK properties (Everett 2003). There are hopes that micro-CHP systems for individual households, which simultaneously provide heat and electricity in a unit about the same size as a domestic heating boiler, will make expansion of CHP in the UK more likely.

However, micro-CHP is still in an early stage of development, with field trials currently underway and results expected in summer 2006 (DEFRA 2004b). Recent reports suggest that these trials are behind schedule, with just five units currently being tested, compared with initial plans to test 6,000 units (ENDS 2004c). By EU standards, 5% of households using CHP by 2050 in DJ-DS does not seem overly ambitious, but either a different technology (i.e. micro-CHP) or considerable institutional and social changes are likely to be required to change the historic UK reluctance to adopt CHP.

Electric heat pump systems are much less well established in the UK and EU than either community-level CHP or condensing boilers. In the UK, householders can currently receive subsidies through the government 'Clear Skies' programme for ground source heat pump systems (Clear Skies 2004). Heat pump technology has been long established, particularly for cooling, and the assumption that all electrical space and water heating by 2050 will be provided by heat pumps is technically feasible, although it currently seems unlikely.

Solar water heating

In the DJ-DS scenario, by 2050 10% of pre-1996 dwellings have solar water heating (SWH) and by 2010 all post-1996 dwellings have SWH. Issues around modelling energy supplied per SWH system are discussed in detail in Appendix 4. The latest estimate from DTI is that the use of active solar water heating has doubled in the last five years, contributing 63.4GWh of domestic hot water energy (DTI 2004a). If each SWH system delivers 1,000 kWh/year (see Appendix 4), this would be equivalent to 63,400 installations. Clearly the industry would have to scale up very considerably to be able to achieve up to 200,000 installations per year by 2010 needed under DJ-DS. There are a number of other barriers to installing SWH, which are discussed below.

For pre-1996 dwellings, the installation of SWH will require significant changes to the existing hot water delivery system. Suitable hot water storage capacity is an essential part of any solar water heating system. For conventional storage hot water systems it is usually necessary to add an additional hot water cylinder or change the existing one to a twin coil cylinder (CAT 2003). This increases the cost and disruption of installing SWH systems.

For hot water systems powered by combi boilers (which make up half of new boiler sales, as discussed earlier), it is difficult to incorporate solar water heating. This is because combis are designed to take cold mains pressure water, and solar systems supply hot or warm low pressure water (CAT 2003). Reading Borough Council has managed a refurbishment project where solar water heating, with its own storage system, was combined successfully with combi boilers (LEARN 2003b). But when Reading's system was specified only two combi boilers on the UK market were guaranteed to accept solar pre-heated water (LEARN 2003a). In addition to the small choice of suitable boilers, the space needed for the additional hot water tank could be a significant barrier to the uptake of SWH for people who want combi boilers.

SWH is not equally applicable in all situations. ETSU (1999) judged that only 50% of the housing stock in the UK was suitable for solar water heating. SWH provides the best results when located on an unshaded south facing roof and is not recommended for use on north facing roofs. SWHs placed on east or west facing roofs are estimated to produce 15% less energy than those on south facing roofs (ESD 2003). From this analysis it seems that Johnston's figure of 100% usage of SWH in new housing from 2010 onwards is optimistic, unless the new housing can be designed and aligned to provide suitable roof space. However, in terms of overall energy use, it makes a relatively small difference – by 2050, installing SWH in just half of new dwellings results in an increase in energy consumption of only 1% in the Demand Side scenario.

Discussion

This section has illustrated some of the barriers that will exist to achieving the technological improvements contained in Johnston's Demand Side scenario. These include problems with compatibility with existing technology or buildings, lack of market incentives and policy measures to achieve change, and resistance to changing the appearance of buildings. To overcome these problems, there will have to be social, cultural and institutional change as well as technological change. This review has deliberately been illustrative rather than comprehensive – identifying some of the barriers to technological progress. More broadly, the following section considers how changes in behaviour or lifestyles could put 60% carbon savings beyond the reach of even the optimistic assumptions in DJ-DS.

4.8 Investigating alternative lifestyle and behavioural futures

4.8.1 Introduction

This section looks in detail at social and behavioural variables and how changes in these factors could affect future energy demand. The purpose is to investigate to what extent plausible combinations of changes in behaviour could compromise future energy savings. It highlights the vulnerability of technological assumptions to changes in behaviour, and the possible interactions between technology and behaviour.

The key variables considered here are hot water demand, internal temperature, number of people per household, rates of demolition and energy consumption by domestic lights and appliances. For each variable, the range of future possible values is discussed. Then the maximum and minimum values are run through the model to investigate how much difference these changes could make to total energy use. Finally, the maximum and minimum values for each variable are combined to create High and Low Energy scenarios. The High Energy scenario reflects the social values which would prevail under the 'individual' Foresight scenarios, while the Low Energy scenario shares social values with the 'community' Foresight scenarios (Chapter 3). Savings are compared for their effect on DJ-BAU, so that these behavioural changes can be easily compared with the technological changes in DJ-DS. This analysis demonstrates the vulnerability of savings identified in DJ-DS (and similar scenarios created for other models) to changes in behaviour and demand for energy services.

A wide range of possible values is considered for the social and lifestyle variables under consideration. Johnston identified likeliness, relevance, consistency and transparency as the criteria for constructing his scenarios. This thesis takes a different approach in one respect - 'likeliness' is not included as a criterion. The reason for this is, as demonstrated in Chapter 3, that the most likely scenarios are those which also generate the greatest increases in carbon dioxide emissions - in order to achieve a significant reduction in carbon emissions some unlikely things may need to happen. High values are chosen from the upper range of what currently seems plausible, and low values are similarly as low as seems possible, in order to give a wide range of futures.

In the numerical analysis, Johnston's BAU values are used until 2004 after which there is linear interpolation from 2005 to 2050, the year for which maximum and minimum values are defined.

4.8.2 Space heating energy demand and internal temperatures

Heating accounts for around 60% of total household energy use. Energy use for heating is determined by the amount of time that the property is heated, the temperature it is heated to and the proportion of the house that is heated (as well as the thermal and ventilation properties of the dwelling). All of these factors can be summarised in a single number – the average temperature of the dwelling over 24 hours. Control of this temperature is the single most important behavioural determinant of a household's energy use and subsequent carbon emissions. So, the key questions are what is this temperature most likely to be in future, what plausible future range of temperatures could occur and what theories of comfort have to tell us about these questions. In addition, how would a future range of temperatures affect energy consumption?

In order to estimate the potential range of future temperatures, it is helpful to investigate why temperatures have been rising over time, and what the main drivers in temperature change have been. The temperature achieved in a household is a function of the desired temperature, the technical capacity of the house and the heating system to achieve that temperature, and the financial capacity of the householders to pay for their desired temperature (DoE 1996). Energy efficiency and fuel prices have been changing so that it has become easier and cheaper to heat to higher temperatures. Houses are (slowly) becoming more energy efficient (DETR 2000d). In addition, most heating systems now have the capacity to reach the occupants' desired temperature: central heating is now owned by over 90% of UK households (94% of English households had central or programmable heating in 2001 (ODPM 2003)). Fuel expenditure is falling as a proportion of income: energy only accounted for 3% of the average household expenditure in 2000/01, compared with 5% twenty years previously (ONS 2003a). Technical and financial constraints to higher temperatures are much reduced. For the majority of households, the desired heating regime is the principal determinant of the heating regime achieved. The question then arises - what temperatures do people want?

Changes in perception of comfort

Both modelling and measured temperature data shows clearly that internal temperatures have changed considerably in the UK (Figure 4.5), increasing by about six degrees over the past thirty years. A range of evidence illustrates how attitudes to temperatures have changed over time and also how the range of acceptable temperatures seems to be wider than is commonly assumed:

- In the English House Condition Survey (EHCS), the 'cold' standard in 1986 (<16°C living room and <12°C hall) had been re-classified as 'very cold' by 1996 (DETR 2000d, DoE 1991b).
- In 1986, the EHCS survey (DoE 1991b) asked the following question: "Overall how satisfied are you with your heating?"[2] Although people at the highest temperatures (>21°C) were more satisfied than people at the lowest, there was a very wide range in the middle (between 21 and 12°C for the living room) at which over 80% of people declared themselves very or fairly satisfied. Over 60% of people at *all* temperatures were very or fairly satisfied.
- The percentage of people very or fairly satisfied with their heating has changed relatively little over the ten years from 1986 to 1996 from 81% in 1986 to 87% in 1996 (DoE 1991b, DETR 2000d). This is despite a significant increase in measured temperature (during equally cold winters) from 18 to 19°C in the living room and from over 16 to nearly 18°C in the hall.
- In a nationally representative survey carried out in 1977, 49% of respondents agreed or agreed strongly that 'it is not generally necessary to heat bedrooms'(Field & Hedges 1977). Evidence shows attitudes have changed considerably over twenty years: by

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[2] Although this question is not identical to asking how content people are with the temperature in their homes, it can reasonably be used as an indicator of thermal comfort as people are unlikely to be satisfied with their heating if it leaves them uncomfortable.

1996, just 3% of English households did not heat bedrooms at the weekend (DETR 2000d).

This evidence reflects changing ideas about acceptable temperatures: as temperatures have increased, thinking about what counts as cold has changed with them. Although it is clear that people lived in colder homes in the past, the evidence indicates that this is not identical with universally lower thermal comfort. The EHCS data showed that although people at the highest temperatures in 1986 were more satisfied than people at the lowest, there was a (perhaps surprisingly) wide range of temperatures over which people reported equal satisfaction with their heating systems. Temperature is therefore not on its own a reliable indicator of comfort.

Likely future temperatures

Indoor temperatures are still increasing in the UK and are generally expected to continue to rise (see below). The ability of most households to achieve high temperatures is improving. Both increasing ownership of central heating (although it now has little further to spread) and an expected continuing drop in spending on energy as a percentage of income point to an increasing ability to achieve higher temperatures. Energy prices are of course subject to change, but central heating is unlikely to be removed in the near future – meaning the technological influence on temperatures achieved and expected will be present for years to come. Given the malleability of 'normal' comfort levels (Shove 2003), a continued rise in temperature should not be seen as inevitable, although it currently seems likely.

Researchers at BRE estimate that living room temperature during occupied periods is unlikely to exceed 21°C and that a temperature about 19°C would be considered adequate elsewhere in the dwelling, giving a 24 hour temperature average of 19-20°C as an ultimate comfort level (Shorrock & Utley 2003). A government paper which considered the temperatures which would prevail in different Foresight scenarios by 2050 (as described in Chapter 3) suggested a narrow range from 20°C in the Local Stewardship scenario to 22°C in the World Markets scenario (DEFRA 2001b). However, another government study using these scenarios assumed that all would converge on 21°C by 2020 (PIU 2001b). Johnston expected the average temperature to reach 21°C in both pre- and post-1996 housing (Johnston 2003a). The differences between these projections is fairly minor, with a general expectation that average internal temperature will increase until it reaches 20-22°C and then stabilise. But is it inevitable that temperatures will rise, or that they will stop rising at around 21°C?

There is evidence that some people are already choosing temperatures above 21°C. In the UK, one study showed residents in nine super-insulated homes exceeding a whole house 24 hour average of 22°C (Ridley 1995). Over 20% of English households in 1996 exceeded a spot temperature of 21°C in their living rooms (DETR 2000d). For comparison, in the USA a household survey in 2001 which asked people what the indoor temperature was during winter when somebody was at home (equivalent to a spot temperature measurement) found an average reported temperature of 21.1°C (Energy Information Administration 2003). The range was from less than 17.2°C, reported in 4% of homes, to more than 23.3°C, reported in 19% of homes. A Swedish study measured indoor temperature measurements in 1200 homes during 1992 (Norlen & Anderson 1993). Indoor temperature was measured continuously for one month. Average temperatures were 20.9°C in single family houses and 22.2°C in multi-family buildings giving an overall average of 21.4°C (the authors did not try to explain the temperature difference between these sorts of dwellings). An indoor temperature of over 23°C was measured in 33% of the apartments in multi-family buildings. It is not clear whether people choosing these high temperatures are an indicator of what might happen in the future, or simply part of the normal variation around an average which may not exceed a 24 hour average of 21°C. However, the data do indicate the desire among some people for temperatures exceeding 21°C.

Understanding indoor temperatures - theories of comfort

Thermal comfort is defined as a person's feeling of warmth. It is not the same as temperature, although there is a connection between the two. There are a number of approaches to explaining the relationship between temperature and comfort. The three approaches – which are linked – can be characterised as physiological, adaptive and social / cultural. Firstly these theories are outlined. Then the theories are used to explore the question of what temperatures might be in future.

The physiological model of comfort suggests thermal comfort is determined by the heat flows between the human body and its environment in order to maintain an energy balance. The main factors which go to make up the sensation of thermal comfort are: air temperature; radiant temperature due to the temperature of surrounding surfaces; air movement; humidity; together with personal factors such as clothing and activity. This theory proposes that there is an identifiable temperature for each level of clothing and activity at which most people will be comfortable.

Much has been done to measure thermal comfort under laboratory conditions. This work has been used to derive standards for thermal comfort to be met in public and commercial buildings. Fanger (1970) was one of the key researchers. He developed a sophisticated method of analysis based upon extensive laboratory studies which enables the percentage of dissatisfied occupants of a room with particular thermal characteristics to be predicted (leading to concepts of the predicted mean vote and percentage people dissatisfied). A small percentage of people are expected to be uncomfortable at any specific environmental condition, due to different individual preferences. Fanger's research has indicated a temperature of around 22°C is generally preferred by sedentary people wearing office clothing. This understanding of comfort is widely used within legislation and underpins projections of future energy use made in government reports such as the English House Condition Survey Energy Report series.

The key criticism of the physiological approach is that the results of field studies have not matched those found in laboratories. As Burberry states:
"*Recent research has cast doubt on the validity of specific fixed temperatures as a close guide to thermal comfort. There is evidence that people adapt their clothing and immediate environment to suit prevailing conditions and, within reasonable limits, are most comfortable when thermal conditions remain fairly stable, irrespective of actual values.*"(1997: 73)

This research has led to the development of the adaptive approach to thermal comfort, which starts not from a consideration of the heat exchange between people and the environment, but from the observation that there is a range of actions that we can and do take in order to achieve thermal comfort (UNL 2003). The adaptive principle states that if a change occurs such as to produce discomfort, people react in ways that tend to restore comfort. It follows from this that comfort temperatures reflect average temperatures. This understanding of thermal comfort has emerged from research on temperature in workplaces, usually offices. It is not entirely clear what insights the adaptive principle has to offer on household temperature, where individuals have reasonable control over their environment and are also responsible for paying the fuel bills.

The adaptive theory of comfort does not necessarily contradict the physiological theory. However, it challenges the over-simplified interpretations of physiological theory, which suggest achieving a certain temperature will lead to comfort. It also stresses the limitations of steady state laboratory studies for predicting comfort in real life situations which are often transient.

What might be seen as a third paradigm of thermal comfort research concerns the social and cultural construction of comfort (Chappells & Shove 2003). This research reveals how comfort is (or has been) culturally relative and is framed by issues of social convention, symbolism and status that cannot be reduced to thermal, physiological or psychological parameters. A simple example of this is the temperatures people seek out and enjoy on sunny holidays are vastly in excess of what would be thought comfortable in a work situation. Anthropological studies have shown there is a wide range of temperatures at which people are comfortable. A related set of ideas concerns the socio-technical construction of comfort and the role of wider systems of provision in shaping domestic thermal norms. Although not disputing the physiological and adaptive approaches, the social / cultural approach takes into account other factors which affect people's feeling of comfort and so claims a wider range of temperatures can be comfortable.

All three approaches to thermal comfort would endorse the statement made earlier that temperature on its own cannot be used as an indicator of comfort. Assuming a future temperature regime where most people are comfortable does not tell us what temperatures will be, unless we also know levels of activity, clothing, humidity, cultural ideas of acceptable temperatures and so on.

Temperature range for investigation

The temperature range to be investigated in the model is 16-23°C. According to Shorrock and Utley (2003) 16°C was the average internal temperature during the early 1990s. It is considered to be the lower minimum temperature safeguarding health (DETR 2000d). An average temperature of 16°C is likely to be characterised by higher levels of clothing and differentiated temperatures within the home with warmer living areas and cooler bedrooms. Better insulated homes would make achieving thermal comfort at lower room temperatures more possible, because of the lack of draughts and radiant cold from walls and windows.

The maximum value of 23°C is a higher figure than usually used, but it is possible that changing ideas of thermal comfort could lead to this becoming the norm. This temperature was exceeded by a significant proportion of Swedish homes in 1992. An average temperature of 23°C would be consistent with high temperatures throughout the house, light clothing and low levels of activity.

According to BRE, the average 24hr internal temperature increased by approximately 1.5°C during the 1970s, and by 2-2.5°C during both the 1980s and the 1990s (Shorrock & Utley 2003). Some of this change in temperature was due to the increasing proportion of centrally-heated homes, which have higher temperatures, rather than temperature increases within centrally and non-centrally heated homes. Thus a maximum rate of change of 1.5°C per decade will be used in the model for both increasing and decreasing temperatures.

By 2050, a temperature of 16°C results in a total energy reduction of 32%, whereas an increase to 23°C would lead to an increase of 15% (Table 4.8). An additional scenario of temperature at 18°C has also been calculated.

Table 4.8: Effects of internal temperature scenarios on UK household annual energy consumption

	Difference from DJ-BAU (%)		
	23°C max	18°C max	16°C max
2010	1.6	1.0	-12.3
2030	7.1	-14.7	-27.9
2050	14.8	-20.5	-32.2

There is considerable concern that, as external temperatures rise under climate change, there will be increasing demand for air conditioning in UK homes. ODPM (2004) has undertaken some preliminary research on the likely uptake of domestic air conditioning if summer temperatures increase. They state that if the temperatures experienced in 2003 were to become the norm, then ownership of air conditioning could increase to 30-40% in the South East of England. Future energy consumption by air conditioning has not been estimated for inclusion in TF-BAU. This is just one of the new uses of energy that is not included in modelling within this thesis, meaning that all future energy consumption estimates are likely to be underestimates (as discussed in Chapter 3).

4.8.3 Hot water demand

Hot water demand could change considerably over the next fifty years. In Johnston's scenarios hot water demand is assumed to reduce from around 43 litres per person per day in 1996 to around 40 litres by 2050. This reduction occurs as a number of occupants install mains pressure spray-head taps and showerheads into their dwellings. This section considers two interlinked determinants of hot water demand. The first is personal demand for hot water, the second is change in technologies related to hot water which may affect how much hot water can be delivered how quickly and consequently affect hot water demand. Both could lead to greater changes in demand than envisaged by Johnston.

Over recent decades household water usage has increased. Today's households use 70% more water than in the 1960s (Hassell 2002). Total use of water per person (hot and cold) continued to rise steadily during the early 1990s, reaching a peak of 154 litres per person per day in 1995. Between then and 2001 it stayed fairly stable at 150 l/person/day (National Statistics 2001). Hot water therefore currently accounts for around thirty per cent of total water usage (43 litres out of a total of 150 litres). Water use in England in 1997/98 was estimated to be in the following proportions: bath / shower / hand basin – 33%; toilet flushing – 25%; clothes washing – 14%; dish washing – 8%; garden use and car washing – 7%, other (including kitchen taps) – 13% (National Statistics 2001). As this includes both hot and cold water, it does not give an accurate picture of how hot water demand is made up – but it indicates that personal bathing /showering dominates demand.

Demand for hot water

Reliable measured data on hot water usage are in very short supply. An EU study suggested that the average EU citizen used 36 litres of 60 °C water per day, with a measured range between 20 litres and 63 litres (NOVEM 2001), however, this was based on very limited monitored data.

An individual's demand for hot water does not arise in isolation. It is affected by the availability and cost of hot water, social conventions on washing, bathing and clothes laundering, water usage of washing machines, whether showers or baths are preferred and so on. Many of these factors are themselves inter-related. It can be argued that the increasing availability and falling cost of delivering hot water has allowed social conventions around bathing to change. So although hot water demand is discussed in relation to the individual this does not imply that individual preferences are solely (or even primarily) responsible for changes in demand.

Shove (2003) presents a complex social analysis of both bathing and clothes laundering. She considers the nature of bathing and how it fulfils many different functions simultaneously: pleasure, duty, as a means of positioning the self in society, and expressive of the relationship between the body and nature. Shove's analysis demonstrates how ideas about the role of bathing and bathing practices have changed over time, and that more but also less resource-intensive conventions of normal practice may arise in the future. She suggests that bathing practices are not locked into an inevitable escalation of resource use. In general, Shove concludes that:

"Looking ahead, what people take to be normal is immensely malleable. There are no fixed measures of comfort and cleanliness and it is perfectly possible that future concepts will be less resource intensive than those of today." (2003:199)

This suggests a wide range of possible future demands for hot water.

Technological systems for delivering hot water

At the moment there are two key trends in hot water installations which will affect the rate at which hot water can be delivered and thus have the potential to affect demand:

- increasing popularity of mains pressure cylinders - increasing the rate at which hot water is delivered;
- increasing installations of combi boilers - decreasing the rate at which hot water is delivered.

Brinkley (2002) estimates that one in six new hot water cylinders are mains pressure ones, as are as many as half of all cylinders going into new homes. This contrasts with traditional UK hot water systems where the hot water tank is fed from a cold water cylinder in the loft (and hot water consequently is not at mains pressure, unlike cold water). The main advantage of mains pressure hot water is that it enables householders to have higher flow-rate showers. The flow rate depends on local water pressure, but can be up to 35 litres per minute (Brinkley 2002), much greater than conventional non-mains pressure systems which deliver water at about 10 litres per minute (Hassell 2002). Thus, all other things being equal, mains pressures showering could use several times the water and energy of its conventional equivalent.

Hot water systems without storage capability, powered by combi (combination) boilers, are becoming increasingly popular in the UK. In 2002, combis accounted for around 50% of all new boiler sales (Brinkley 2002). These boilers are popular because they do away with the need for hot water storage (in cylinders), and tanks and associated pipework in the loft, and cost saving offsets their higher price than conventional boilers. Combis are cheaper to install than a conventional system (Brinkley 2002). The disadvantage is the lower rate at which hot water can be delivered (compared with a storage system) - this means that combi boilers are generally considered most suitable for smaller properties and smaller households, where there will not be multiple simultaneous demands for hot water. Running a bath with a combi system could take two to three times as long as with a conventional system, and so use of showers could be favoured. However, at the same time, a combi system never runs out of hot water - potentially facilitating an increase in hot water use.

Hot water demand range for investigation

With technological trends pointing in opposing directions and the possibility of social norms on bathing and clothes washing moving in different ways, a wide range of per capita hot water demand is possible in the future. The values used in the model are 20 litres and 80 litres in 2050, respectively half and twice the values in Johnston's BAU. The value of 20 litres is based on the lowest measured value in the EU study quoted earlier (NOVEM 2001). This would be consistent with greater use of combis with their lower flow rates, with short showers becoming preferable to power showers or frequent bathing. The figure of 80 litres is greater than that currently seen in the EU. However, given the capacity of new mains pressure water systems to increase shower water use by a factor of three, a higher maximum of 80 litres would be consistent with more frequent high pressure showers or a preference for bathing over showers. This rate of change of water use, a halving or doubling over fifty years, is similar to the 70% increase over forty years seen since the 1960s (Hassell 2002).

By 2050, a water demand of 20 litres per person per day results in a total energy reduction of 5%, whereas an increase to 80 litres would lead to an increase of 11% (Table 4.9).

Table 4.9: Effects of hot water demand scenarios on UK household annual energy consumption

	Difference from DJ-BAU (%)	
	20 litres by 2050	**80 litres by 2050**
2010	-1.2	2.4
2030	-3.0	6.1
2050	-5.4	10.8

4.8.4 Lights, appliances and cooking energy demand

In the DJ-BAU scenario, energy consumption per household from lights, appliances and cooking is 10.5% lower in 2050 than it was in 1996. The decreases in energy consumption come primarily from the cold appliances (fridges and freezers), wet appliances (washing machines, dishwashers and tumble driers) and cooking, with energy use by consumer electronics and lighting increasing. In the DJ-DS scenario it is assumed that electricity use by lights and appliances halves by 2020 and that energy use in cooking fall by around a quarter by the same date.

It is difficult to separate issues of usage and ownership of lights, appliances and cooking from new technologies which might tend to increase or decrease consumption. This is particularly the case for higher energy usage where new technologies tend to drive new patterns of demand for additional energy services. There is no comparable key behavioural or social variable for these end uses which parallels indoor temperatures or hot water consumption in determining space and water heating energy use.

Norgard & Christensen (1994) have suggested that it would be possible to live a high quality life using just 250 kWh electricity per person per year, with three people sharing a household, making household consumption of 750kWh. This level of consumption would rely on lower usage and ownership of some technologies as well as technological improvements. This is less than a quarter of current UK household electricity annual consumption (for lights, cooking and appliances). However, experience in a small number of monitored UK low energy houses has not shown particularly low electricity use, with the range of electricity used per household for lights, appliances and ventilation being 2,290 – 4,050 kWh/ year (analysis based on Best Practice Programme 1997). A number of the case study households which will be presented in Chapter 6 had lower electricity use than this. Historic evidence shows that energy use for lights, appliances and cooking has increased by 53% per household between 1970 and 2001 (Shorrock & Utley 2003).

The low value assumption is that energy use in these sectors could reduce to around half of the DJ-BAU value in 2050, a similar assumption to that made in DJ-DS (but in this case not making any assumption of technological improvement beyond that embedded in DJ-BAU). In a high consumption future, there would be higher ownership of appliances, higher usage and adoption of appliances which have not yet been invented. The assumption here is that energy consumption for these end-uses could double by 2050, which is a slightly higher rate of increase than that since 1970, but certainly plausible if there are no major brakes on demand.

By 2050, a fall by half in energy use in lights and appliances results in a total energy reduction of 11%, whereas a doubling would result in an increase of 23% (Table 4.10).

Table 4.10: Effects of lights, appliances and cooking scenarios on UK household annual energy consumption

	Difference from DJ-BAU (%)	
	2 * BAU	**0.5* BAU**
2010	2.3	-1.2
2030	9.0	-5.4
2050	23.0	-11.0

Because electricity is a higher carbon fuel than gas, this would lead to an even greater increase in carbon dioxide emissions. So under the double DJ-BAU scenario, carbon dioxide emissions would be 2.9% higher in 2010, 16.4% higher in 2030 and 32.7% higher in 2050 than in DJ-BAU if Johnston's projections for the annual carbon intensity of electricity to 2050 are used. These projections are described in Section 4.9.

4.8.5 Household size

The influence of population projections on household numbers has already been discussed earlier in this chapter. The other key factor is the size of households, that is, how many people live in the average household[3]. The number of people per household has fallen over recent decades. In 1971, there were 2.9 people per household, whereas by 2003 it had reduced to 2.4 (National Statistics 2004a). This pattern is common to the rest of Europe, with data showing that the average household size in the European Economic Area excluding Ireland fell from 2.82 in

[3] The number of households is simply defined as the total population divided by average household size. Because only occupied homes are of interest for energy modelling, the number of second homes and empty homes does not have an influence on household numbers. Thus the number of dwellings will be higher than the number of households.

1980 to 2.49 in 1995 (EU 2001). In 1995 some countries already had smaller household size than the UK does now, with Germany having the smallest households at 2.21 people, followed by Denmark at 2.26 and Sweden at 2.27 (EU 2001). The changing size of households is related to demographic and social change, with key factors including the ageing population, lower marriage rates, increased divorce rates and the falling number of children per woman. In particular, the proportion of one person households has increased significantly, in the UK rising from 18% in 1971 to 29% in 2003 (National Statistics 2004a). Household size tends to influence the supply of the physical housing stock rather than the other way round. The dwelling stock is expected to expand to meet the increased demand for housing generated by increasing household numbers.

Johnston's projections (DJ-BAU and DJ-DS) assume that household size will continue to fall until it reaches 2 persons per household in 2040, after which size remains the same. However, a wider range of future household sizes will be investigated.

Maximum size of households

The physical nature of the housing stock is unlikely to be the primary barrier to increasing household size. In 2002/03 just 6% of new dwellings were built with one bedroom, whereas 36% had four or more bedrooms (National Statistics 2004a) – so houses are large enough to accommodate larger households. It will be social and demographic change which determines household size.

It is assumed (by the author) that current trends towards greater individualisation will reverse, and that the household size in 1971 of 2.9 could be achieved again by 2050. However, if household size did increase to 2.9 by 2050, because the UK population is not expected to increase very much, household numbers would actually decrease below those in 1996 by about two and half million. This would require around 50,000 demolitions per year and that no new dwellings were built.

Minimum size of households

Technically, the minimum household size is one person per household. However, a scenario where everyone lives alone (including children of all ages) is clearly unrealistic. Johnston used a minimum of two people. The minimum used here is 1.8 people per household (which could be made up of 40% one person households, 45% two person households, 10% three person households and 5% four person households).

Modelling the effect of household size

The way the model works is that the number of new houses per year is determined by the replacement of pre-1996 homes (lost through demolition) plus the demand for additional housing generated by increasing household numbers. So in all scenarios where household size varies (and demolition rates are the same) there is the same number of pre-1996 homes, which dominate energy consumption. Because differences in the number of houses under varying household size scenarios are for new homes only - the differences in energy consumption due to changing household size, and consequent household numbers, are perhaps lower than might be expected.

By 2050, a fall to 1.8 people per household would result in an increase in energy consumption of 6%, whereas an increase towards 2.9 people by 2050 would result in a decrease of 12% in energy by 2030 (Table 4.11).

Table 4.11: Effects of household size scenarios on UK household annual energy consumption

	Difference from DJ-BAU (%)	
	1.8 people/hh	**2.9 people/hh ***
2010	0.4	-3.1
2030	1.7	-11.5
2050	6.2	n/a

* The 2.9 people/hh scenario makes little sense after 2030 because there are no new dwellings required due to contracting numbers and the model assumes negative numbers of new houses.

One of the weaknesses of the modelling is that it does not allow variation in energy use depending on the number of people in the household, with the exception of water heating. Other forms of energy use are also likely to increase as the number of occupants per household rises. Thus the model probably overestimates the savings available from assuming people live in larger households.

4.8.6 Rates of demolition

New build houses are expected to use considerably less energy and be responsible for lower carbon dioxide emissions than pre-1996 dwellings throughout their lifetime, even under the DJ-DS scenario. Thus an increased rate of demolition means that lower energy consuming dwellings are replacing higher energy dwellings - resulting in energy savings. The question is how significant the savings could be.

In Johnston's BAU scenario, demolition rates stay constant at 16,700 from 1996 to 2039. However the rate increases dramatically between 2040 and 2045 and then stays at a high level. This change in demolition rates was introduced by Johnston to ensure that as household numbers fell slightly between 2040 and 2050, construction of new houses would continue at a reasonable rate. If the demolition rate was not increased, no new houses would be constructed. The main grounds for his decision was that it was very unlikely that the house building industry would be largely wiped out by the lower demand for new housing.

To understand the boundaries of possibility for demolition rates it is useful to look at the history of demolition over recent decades. This is carried out in detail in Appendix 5. In summary, demolition rates have been far higher in the past than at present, being around 90,000 per year in 1939. Demolition rates reached a post-war peak around 1970 with 70,000 properties demolished per year. Since then demolition rates have decreased considerably, particularly for the privately owned housing stock. It is estimated (based on government sources, as explained in Appendix 5) that 24,400 dwellings were demolished in England in 2000/01. This is equivalent to demolishing around 0.1% of the English housing stock per annum, i.e. houses having to last 1000 years before replacement. In Scotland, from 1996 to 2001 the demolition rate has been higher, with around 0.2% of the stock demolished per year (Scottish Executive 2002). In Northern Ireland, 0.15% of the stock was demolished per year on average in 2002/03 and 2003/04 (DSD 2004). In Wales, an average of 600 dwellings were demolished annually between 1996/97 and 2003/04 (Statistics for Wales 2004). This equates to around 0.05% of the housing stock per annum. However, as this figure relates only to government-funded demolition activity it may be an underestimate of the Welsh total (see Appendix 5 for an explanation of different types of demolition). At current English rates of demolition, 94% of houses built by 2000 will still be standing in 2050. Rates of private housing demolition are much lower at 0.02%, implying these houses will have to last for 5000 years.

Range of future demolitions rates

The range of demolition rates to be explored in the model is between half of the current rate of demolition, 0.05 of the stock per year, up to a maximum of 0.5% of housing per year. The current demolition rate is already historically very low (at 0.1%), half the present rate seems a reasonable estimate of a long-term minimum. The reason for choosing 0.5% as a maximum is that when demolition rates were at a post-war high in the early 1970s, 0.4% of the housing stock was demolished per year. In addition, given the expected changes in UK climate described in Chapter 2, demolition rates could well increase over time as properties are lost to rising sea levels and increased flooding incidents, or are removed as they become uninsurable due to these and other climate risks. A demolition rate of 0.5% per annum would require the capability of replacing 157,000 dwellings per year in 2050 in addition to the new dwellings required by the change in household numbers, compared with a dwelling completion rate in 2002/03 of 184,000 per year (National Statistics 2004), which should not prove impossible.

By 2050, a demolition rate of 0.05% per year leads to an increase in energy consumption of 2%, whereas an increase to 0.5% by 2050 would result in a decrease of 5% (Table 4.12).

Table 4.12: Effects of demolition rates on UK household energy consumption

	Difference from Johnston BAU (%)	
	0.05% per year	**0.5% per year**
2010	0.0%	-0.1%
2030	0.0%	-2.1%
2050	1.7%	-5.1%

These calculations are based on replacing the average pre-1996 dwelling, whereas if an accelerated demolition policy was put in place in real life, the least efficient dwellings would be targeted for replacement and savings are likely to be higher. The embodied energy involved in creating new dwellings would also have to be considered, but preliminary analysis has suggested this is not very significant compared with the lifetime energy in use in dwellings (Fawcett 2002) – see Appendix 6 for details.

Proposing a considerably increased demolition rate does of course raise questions about practicality. There is every reason to believe that political and economic difficulties associated with mass demolition of privately-owned housing would be more severe than in the 1970s. Nevertheless, a very low rate of demolition is not without its problems. It is widely recognised that the current very low rate of housing demolition is leading to an unrealistically long expected lifetime for houses (Balchin & Rhoden 1998, Revell & Leather 2000, Chartered Institute for Environmental Health 2002). Within the EU, the UK has the second largest proportion of pre-1919 housing. It also has the lowest rate of demolition in the EU. Other countries with an ageing housing stock (such as Austria, France and Belgium) have higher levels of clearance (Revell and Leather 2000). However, this has not led to many direct calls for increased demolition rates. Unlikely as an increased demolition rate may seem at present, given the right political climate and suitable financial arrangements, it might be achieved in future.

There are a number of ways in which increased demolition rates could be encouraged. For example, if properties had to reach a minimum standard in terms of their carbon emissions before sale or rental, this would increase the attractiveness of demolishing a (less valuable) sub-standard home and replacing it with a more valuable new one. Alternatively, increased density of development could be encouraged through the planning system. This would make it easier for developers to replace existing old homes with new higher density development (as happens to a limited extent already). However, a policy like this would also have impacts beyond housing policy, e.g. on local traffic patterns. Finally, the government could offer direct financial assistance to owner occupiers in sub-standard housing to cover some or all of the costs of demolition and re-building, with the government getting back its investment by benefiting from the increased value of the replacement dwelling.

4.8.7 Combination into high and low energy scenarios

The various factors above can be combined into high and low energy scenarios to see what the maximum effect of these values is in combination. In each of the scenarios the values listed below are those achieved in 2050, with linear interpolation from Johnston's values for 2004.

High energy scenario (TF-HighE) – values in 2050

- 80 litres hot water demand per person per day
- 23°C internal temperature
- household size of 1.8 people
- demolition rate is 0.05% of the stock per annum
- energy consumption by cooking, lights and appliances is two times that in BAU scenario

Low energy scenario (TF-LowE) – values in 2050

- 20 litres hot water demand per person per day
- 16°C internal temperature (variation with 18°C internal temperature)
- household size of 2.9 people
- demolition rate is 0.5% of the stock per annum
- energy consumption by cooking, lights and appliances is half that in BAU scenario

The general trends of increasing personal consumption and greater individualisation of society which are embodied within the High Energy scenario match those within the Foresight World Markets (WM) scenario (which has been identified as the scenario most like conventional development). By contrast, the values embodied within the Low Energy scenario are those of reduced personal consumption and stronger communities with people choosing to live together in larger households. These match the Foresight Local Sustainability values.

The low and high energy scenarios are shown in comparison with Johnston's BAU projection (Figure 4.7) . The low energy scenario is shown with a variation where the average internal temperature is 18°C rather than 16°C. Johnston's Demand Side scenario is also shown for comparison, as is TF-BAU.

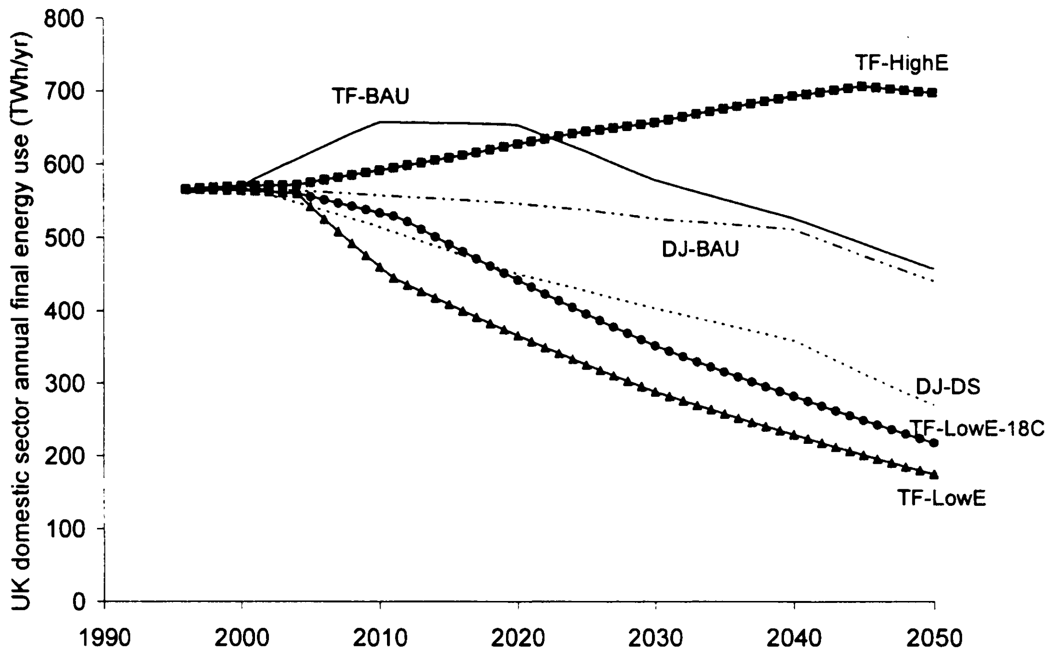

Figure 4.7: Low and high energy scenarios, UK domestic sector, 1996-2050

These scenarios demonstrate the considerable variation in energy consumption which might occur, even with no additional technological improvements beyond those included in Johnston's BAU scenario. In fact both TF-LowE and TF-LowE-18C save more energy than the technologically-improved DJ-DS scenario. Energy consumption is 58% higher in TF-HighE than DJ-BAU in 2050 and 60% lower in TF-LowE. TF-LowE achieves 69% energy savings by 2050 compared with 1996, clearly demonstrating that social / lifestyle changes can, in theory, be very powerful forces for energy saving. However, TF-HighE also demonstrates how social and lifestyle influences could lead to considerably higher energy consumption than is currently expected.

Figure 4.8 shows the effect of combining TF-HighE and TF-LowE with DJ-DS. In other words, the figure shows the result of a combination of social change towards higher and lower consumption patterns with maximum technological improvements.

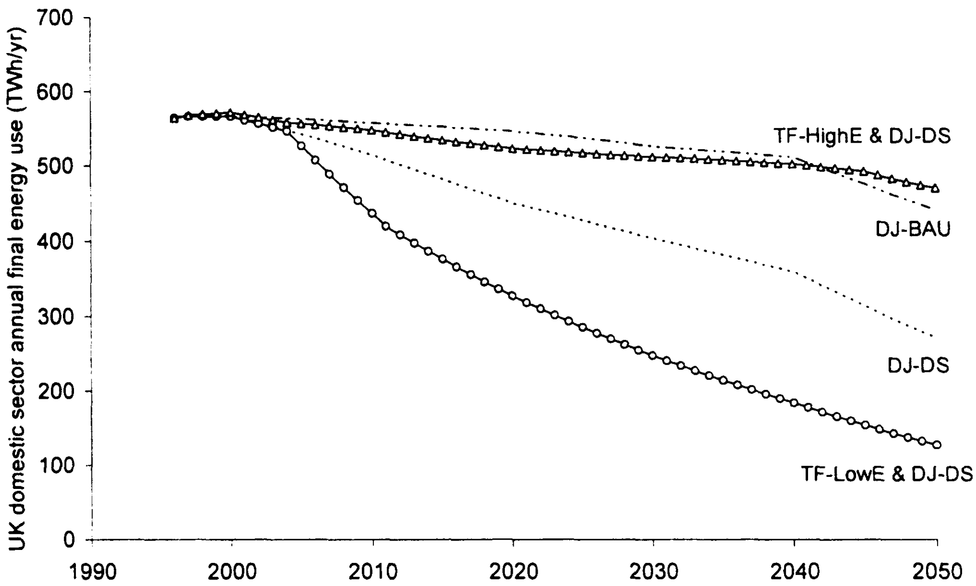

Figure 4.8: Low and high energy scenarios combined with DJ-DS, UK domestic sector, 1996-2050

The TF-HighE and DJ-DS scenarios in combination result in slightly higher energy use than in DJ-BAU by 2050, and energy consumption in 2050 is just 17% lower than in 1996. The scenario TF-LowE & DJ-DS results in saving 77% energy by 2050 compared with 1996.

The lifestyle and behavioural variations identified in the TF-HighE and TF-LowE scenarios are based largely on today's ideas about what is an acceptable level of energy service. They do not designate upper or lower limits to socially-driven consumption, and are clearly just two of the very many different scenarios which could have been developed. For example, a linear projection of energy use 1970-2003 up to 2050 would give total energy consumption then of 760 TWh, a higher total than in TF-HighE. (Remember that projections of past trends incorporate the effect of previous introductions of new technologies, which by definition are excluded from bottom-up modelling.) There are also some more radical views of how much lower energy consumption could be (e.g. Norgard & Christensen 1994).

In conclusion, a combination of social and lifestyle changes has been shown to be very powerful in moving future energy consumption either upwards or downwards. Under the TF-HighE scenario, the technological responses that Johnston has identified in his Demand Side scenario would not be any where near sufficient to reduce carbon dioxide emissions by 60% by 2050, only 17% savings could be achieved. This demonstrates the need to have some type of cap on carbon dioxide emissions from energy use, because otherwise social and lifestyle change could easily increase demand for energy services beyond the point at which efficiency options could be effective in reducing energy use sufficiently.

4.9 Supply side variations

4.9.1 Introduction

So far the analysis in this chapter has been based largely around energy use rather than the subsequent carbon dioxide emissions, which are of most concern. Carbon dioxide emissions depend on the fuels used to supply this energy demand, and, in the case of electricity, the fuels used to produce it and the efficiency of its production, transmission and distribution. The ratio of gas:electricity use stays almost constant in DJ-BAU - gas accounts for between 73 and 75% of total energy use over the whole period of modelling. The carbon intensity of electricity is expected to change over time. However, the carbon intensity of gas is not - because the chemical nature of natural gas (methane) will not change. So the carbon intensity of electricity is crucial to influencing changes in carbon dioxide emissions.

4.9.2 Carbon intensity of electricity

1990 to 2010

Carbon intensity figures are not published by the government on a regular basis. Indicators of carbon intensity since 1970 have been published (DTI 2004b), but actual values are not available from this report. The values in the graph below have been calculated by the author using a combination of data on carbon emissions from the power generation sector (DTI 2004b) and electricity 'final consumption' figures from Table 5.2 in the Digest of UK Energy statistics (DTI 2004a). So the carbon intensity is based on all electricity provided for final consumption in the UK, including net imports, and carbon emissions from the UK generation sector. No temperature corrections have been made to the data. These figures differ by up to 10% from those published by DEFRA for the years 1990-97 (DEFRA 2001a), but DEFRA do not explain their methodology in full, so it is not clear why this is the case. In 2003, the carbon intensity of UK electricity was 0.136 kgC/kWh (based on 'provisional' carbon emissions data).

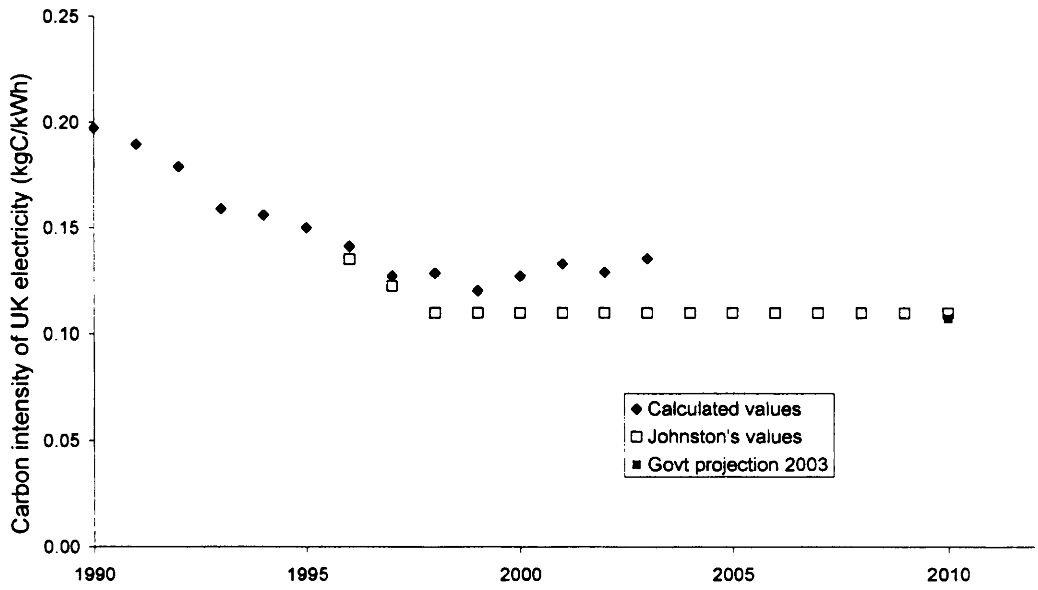

Figure 4.9: Carbon intensity of electricity, UK, 1990-2003 and projections to 2010

The carbon intensity of electricity has fallen considerably between 1990 and 1999 in the UK (Figure 4.9). However, from 2000 high prices of gas have increased the share of coal generation somewhat, leading to an increase in carbon intensity. The key factor in the overall fall of carbon intensity since 1990 has been the huge increase in the use of gas for generation and the consequent falling percentage of generation from coal and oil (Table 4.13). The figures in Table 4.13 are presented on a fuel input basis, i.e. based on the volumes of fuels input to power stations. However, figures on this basis do not account for the different efficiencies with which fuels are used in power stations. The alternative way of presenting this data is by fuel on an electricity output basis, which would reduce the contribution of coal and nuclear fuels and increase the contribution of gas (by about five percentage points in 2003) compared with the fuel input basis, because of the higher conversion efficiency of gas (DTI 2004a).

The percentage gas contributes to electricity generation has risen from less than 1% in 1990 to 32% in 2003. During the same period, there has been a small percentage increase in the contribution of carbon-free nuclear power and renewable electricity and lower carbon combined heat and power (CHP).

Table 4.13: Fuels used to generate electricity, UK, 1990 and 2003 (fuel input basis)

Fuel	1990 (% share)	2003 (% share)
Coal	65.3	38.0
Oil	11	1.5
Gas	0.7	32.2
Nuclear	21.3	23.1
Renewables[4]	0.8	3.3
Other fuels (mostly coal derivatives) + net imports	1.0	1.9

Source: DTI 2004a with non-hydro renewables data for 1990 from DoE 1991a

The carbon intensity of electricity is expected to continue to change in future. The current opinion of DTI is that it will fall by another 17% by 2010 from 2002 values, to reach 0.11kgC/kWh (DTI 2003c). Johnston made a very similar projection for 2010 to that by the DTI, as Figure 4.9 demonstrates. However, Shorrock (2003) suggests that the strong reductions in emissions due to electricity supply industry changes that occurred in 1990s are probably coming to an end.

After 2010

The future carbon intensity of electricity depends on the generation mix, which is itself influenced by changes in prices, availability of fuels and generation technologies. The uncertain future of all of these factors makes it is increasingly difficult to make estimates of the carbon intensity of electricity beyond 2010.

Beyond 2010, Johnston assumes that the carbon intensity of electricity will fall in all scenarios, from 0.135 kgC/kWh in 1996 to 0.090 kgC/kWh by 2050 in the BAU and Demand Side scenarios (a fall of 33% from 1996) and to 0.050 kgC/kWh in 2050 in the Integrated scenario. In the BAU and Demand Side scenarios he uses Environmental Change Institute projections to 2020 (Fawcett, Lane, & Boardman 2000) and assumes a gradual reduction in carbon intensity thereafter. The decrease in energy intensity of electricity in the Integrated Scenario is based on a number of developments in the supply side: increasing the efficiency of energy conversion, by technologies like advanced combined cycle gas turbines; displacing electricity production from more carbon intensive fuels; increased use of renewable energy; development of advanced fuel cells; more nuclear generation; capture and storage of carbon dioxide emissions. Some of these assumptions are very speculative. For example, the use of capture and storage of carbon dioxide

[4] The UK government presents data on renewable electricity on three different bases. The 'international' definition of renewable energy would lead to a lower percentage contribution of 2.67% in 2003, because imported renewable electricity and that from non-biodegradable waste are excluded (DTI 2004a).

emissions, known as carbon sequestration, is currently in the very early stages of research and there remain many questions yet to be answered which are critical to its wide application (Gough, Shackley, & Cannell 2002). The government has recently confirmed that it does not expect projects to capture and store CO_2 to be viable before 2020 (ENDS 2004a).

In terms of mainstream options, gas is expected to be the most important fossil fuel in the generation mix to 2050 (DTI 2003b, PIU 2002). The other key factors which will determine future carbon intensity of electricity are the contributions to be made by nuclear energy and renewables. The future contribution of nuclear power is particularly uncertain. The last nuclear reactor to be built in the UK was Sizewell B, which came into full operation in 1996 (Hillman & Fawcett 2004). At present, no new ones are planned and, if none are built and the life of existing stations is not extended, there would be only one plant still operating by 2025 (DTI 2003b). As its contribution declines, carbon dioxide emissions from electricity will increase unless all current nuclear capacity is replaced by renewable sources. Recent government statements have not given a lead on the future of nuclear power. The Energy White Paper stated: *"We do not ... propose to support new nuclear build now. But we will keep the option open."* (DTI 2003b:44). As stated earlier, there is widely expected to be a gap between the government's ambitions for renewables and their contribution over the next few years. Presently, it does not seem likely that renewable energy will make up the deficit of non-fossil fuel electricity that will emerge as nuclear stations close down.

There are many possible scenarios under which the carbon intensity of electricity could rise. For example, if new nuclear capacity is not brought on line, or if a very significant increase in renewable electricity proves not to be achievable, or if there is a return to greater use of coal or oil, then carbon intensities would rise. It can be argued that Johnston's projections of carbon intensities in the BAU and DS scenarios, as well as the Integrated Scenarios, are optimistic. Two possible alternative scenarios, that the carbon intensity is the same in 2050 as it was in 2003, or that it increases back to the 1990 value by 2050, and the effect this would have on carbon emissions under the DJ-DS scenario are shown in Table 4.14. Carbon intensities at 2003 values in 2050 would lead to an 18% increase in carbon emissions compared with DJ-DS, and a return to 1990 values then would lead to an increase of 43%. As a result of a return to 1990 values, carbon emissions would only fall by 44% from 1996 values, rather than the 58% in DJ-DS.

Table 4.14: Variations in carbon intensity of electricity, and their effect on carbon savings under DJ-DS

Carbon intensity	Domestic sector annual carbon emissions 2050 (MtC)	Change from DJ-DS (%)
DJ-DS	16.1	
Stays constant at 2003 value until 2050	18.9	+18
Increases to 1990 value linearly by 2050	23.0	+43

This analysis demonstrates both the importance of the carbon intensity of electricity and suggests that its continued reduction is far from assured.

4.9.3 Gas as a heating fuel

In terms of current mainstream energy sources for water and space heating, gas is the lowest carbon option there is. It has lower carbon emissions per kWh than solid fuels, oil and electricity. Therefore projections which assume gas will retain its current dominance are a kind of 'best case' for heating fuels. Is it plausible that gas will be the major fuel over the whole period to 2050? If not, how might this affect the carbon intensity of energy use?

There are good reasons to believe that gas could remain a very important fuel. The gas delivery infrastructure is already in place in most areas of the UK and over 80% of households are connected to the gas network (Fawcett, Lane, & Boardman 2000). Gas supplies are expected to still be available in 2050 on the world market, subject to geopolitical concerns. Supplies of oil, probably the key competitor fuel, are thought less certain to be available at low cost in 2050 (PIU 2002). Solid fuel use has been falling over recent years for many reasons, including restrictions on use due to local air quality concerns, and the greater difficulties attached to handling, usage and storage compared with oil and gas. In the PIU (2002) study on the future of energy, gas was expected to remain an important fuel under all the different Foresight Scenarios to 2050. Thus, gas is widely expected to retain its position as the key heating fuel.

However, although gas appears to have many inherent advantages as a fuel, changes in availability and relative prices could be sufficient to change choices about home heating fuels. This might be particularly likely under a future like the Provincial Enterprise Foresight scenario mentioned in Chapter 3, where there is more focus on the national economy rather than international trading. If 20% of current gas users switched to using (British) coal, carbon emissions would increase in DJ-DS by 8% at 2050. In this example, the increase in emissions is not hugely dramatic, but it could be important should people switch away from gas to other fossil fuels in significant numbers.

There are two main options for a lower carbon space and water heating fuel than gas. These are biofuels and renewable or nuclear electricity. Supplying large amounts of electricity at lower carbon intensity than gas would imply a vast expansion of the nuclear industry, which currently seems unlikely. Johnston mentions the possibility of biomass based heating fuels but concludes there is little immediate prospect of this making a significant contribution. At present, over three quarters of renewable energy is used to create electricity rather than heat (DTI 2004a). Biomass could be either burned in homes or at central CHP plants as a substitute for gas. A new report from the Royal Commission on Environmental Pollution has suggested that the government should create 'renewable heat' targets, aiming to perhaps supply 5% of heat by 2020 from renewable sources such as biomass and solar thermal (RCEP 2004).

4.10 Summary and conclusions

This chapter has been concerned with a detailed challenge to the claim that 60% carbon savings by 2050 through technology improvement and renewable energy can be achieved. Although Chapter 3 had already established general arguments for doubting claims of potential future savings, this chapter looks at one particular bottom-up model (Johnston 2003a) and demonstrates clearly that there are many grounds for concern that the projected savings will not be achieved. Johnston's model is just one of many which suggests significant savings can be achieved through technological change, as illustrated in Chapter 3, so the analysis presented would have been similar had a different model been chosen.

Business as usual and reference case projections from Johnston (2003a) and BRE (Shorrock et al. 2001) both suggest a levelling off in and then reduction in energy demand between now and 2020 (BRE) or 2050 (Johnston). However, these projections, when compared with the historical evidence, look optimistic in terms of the expected reduction in energy demand.

Johnston's model has been replicated for use in this thesis. The DJ-DS scenario showed that 50% energy and 60% carbon savings could be made by 2050 by a combination of demand-side renewables, energy efficiency and a reduction in the carbon intensity of electricity. Although DJ-DS is generally technologically conservative, relying on technologies that have a proven track record, there are many non-technical barriers which could jeopardise the envisaged technology improvements. Three of the technologies were chosen for further investigation. It was shown that there could be considerable non-technical problems with achieving the uptake rates assumed in DJ-DS.

Having considered the technical aspects of Johnston's energy saving scenario, social and lifestyle changes which could affect future energy demand were identified. Key factors which could vary were identified, with the most critical factor being the internal temperature of homes. Because of its importance, considerable attention has been paid to temperature, including a comprehensive review of data on internal temperature in UK houses which combines modelled and monitored values from a number of different studies. Consideration of a number of different types of evidence, including current trends, past experience, and data from other countries, led to identification of possible minimum and maximum values for these factors by 2050. These were combined in a High and Low Energy scenario. TF-HighE suggested that energy consumption could be 58% greater in 2050 than DJ-BAU. Like all bottom-up scenarios, TF-HighE does not include as yet unknown energy uses and so is an underestimate of potential future energy use. TF-LowE suggested that energy consumption could be 60% lower in 2050 than DJ-BAU.

Developing these scenarios has clearly demonstrated that a combination of escalating demand in several areas of consumption, and social change, could lead to energy consumption considerably higher than that projected by Johnston for 2050. This increase in energy demand would outstrip the capability of currently known technology to reduce carbon emissions by 60%. Such analysis demonstrates that current modelling of future energy use and potential savings is not based on anything like a 'worst case' scenario. Conversely, social and lifestyle changes could alternatively lead to much lower energy demand than Johnston envisaged.

Future carbon dioxide emissions will be determined by the fuels used as well as household energy demand. The analysis here has demonstrated both the importance of the carbon intensity of electricity, and suggested that its continued reduction is far from assured. In addition, although gas is likely to remain as the most important water and space heating fuel, there is a possibility that higher carbon fuels could increase their market share. The potential for additional carbon emissions is clear.

The analysis in this chapter has highlighted a number of issues about the use of bottom-up models and has identified missing data. For example, it has highlighted how little is known about the new methods of delivering hot water and how this might affect usage. In this example, and others, the linkages between behaviour and technology have been stressed.

Finally, a carbon saving strategy which relies solely on energy efficiency and renewable energy does not provide any mechanisms to restrain demand, without which expected savings may not be achieved in reality, and certainly cannot be guaranteed. The analysis in this chapter points to the need for an over-arching carbon reduction framework, which can incorporate and encourage savings from energy efficiency, renewable energy, social change and lifestyle alterations. The following chapter proposes that personal carbon allowances could provide just such a framework.

Chapter 5: Introducing a new policy: personal carbon rations

5.1 Chapter overview

In earlier chapters, several key arguments have been presented, which are necessary precursors to the ideas pursued in this chapter. To re-cap, the critical propositions are:

1. Evidence from Chapter 1 demonstrated that climate change is an extremely serious global environmental problem and urgent action is required to reduce greenhouse gas emissions.
2. However, current action is far from sufficient. Chapter 2 showed there is little evidence that the UK is moving towards a lower carbon economy. The government is not expected to meet its 20% carbon reduction target by 2010.
3. The government's radical target for 60% reduction in emissions by 2050 has not been matched by the equally necessary radical thinking about policies to achieve the target. There is a large policy gap.
4. Historical analysis in Chapter 3 and bottom-up modelling undertaken in Chapter 4 suggest that energy efficiency improvements alone cannot guarantee a reduction in carbon emissions from the domestic sector. In the past, potential savings from efficiency have been overwhelmed by increases in demand for energy services, and this is likely be the case in future too.

This chapter introduces a new policy which responds to the seriousness of climate change and provides a fair and effective way of making the necessary carbon savings in the domestic sector. The policy is personal carbon rations for all UK citizens. Carbon rationing would provide an overall mechanism for making savings from a combination of energy efficiency, renewable energy and social and behavioural changes. In addition, it will be argued, this policy opens up the possibility of increasing carbon savings beyond 60% by 2050.

Firstly personal carbon rationing, as investigated in this thesis, is described in some detail. Future rations up to 2050 will be defined under different carbon emissions scenarios. The underling principles which support carbon rationing will be elaborated. Then the existing literature on carbon rationing and similar policies will be summarised to show how the definition in this thesis emerges from earlier work. In the following section, the principles underlying rationing and how it fits with global carbon emissions reduction are considered. 'Contraction and convergence', the most promising basis for a global agreement on carbon reductions, is described and the connection with UK carbon rationing is explained. Next, practical aspects of introducing rationing are discussed. Firstly, Britain's most important example of mass rationing, food rationing during the second world war, is described and lessons are drawn from that experience for carbon rationing. Then other practical issues of administration are considered. Finally, the wider social and economic implications of carbon rationing are briefly considered.

5.2 Methodology

The key aim of this chapter is to describe what carbon rationing is and how it could operate in practice, and arguments and descriptions have been developed to that end. These cover the principles on which carbon rationing would be based and practical operational details for the scheme. The prospects for carbon rationing are investigated by considering how existing policies could be adapted to support rationing.

This description of carbon rationing is situated within the existing literature by means of a literature review. The characteristics of other suggestions for rationing-type scheme are compared with the one described here. However, little has been developed on this topic previously, so there is limited material.

Existing data is used to perform original calculations. Secondary data is used to estimate how much of the UK's carbon emissions including air travel are the direct responsibility of individuals (rather than being emitted by the commercial and industrial sectors). Then, data on current emissions of carbon in the UK and future targets are used to calculate what future rations would need to be. Variations on rations, depending on carbon reduction targets and on the way in which rationing is introduced and progressively tightened over time, are also calculated.

Historical evidence has been used to describe the policy responses to two different crises, from which lessons may be drawn for responding to climate change. Firstly, a national policy, that of food rationing during the second world war is described. The characteristics this shares with carbon rationing are identified, as are the many differences between the two forms of rationing. Secondly, the international response to damage to the ozone layer is described. Again, the lessons this may offer for responses to climate change are identified.

5.3 Description of personal carbon rations

5.3.1 Introduction

Before reviewing the existing literature, the concept of personal carbon rationing developed in this thesis is described in some detail. Carbon rationing as presented here is not an original idea. As explained in the literature review (in section 5.4), there has been earlier work on carbon rationing and allied policy concepts. However, what is novel in this chapter is the detail in which carbon rationing is described and worked out, and how past experience and present data are used to investigate the implications of the policy in this and the following chapter.

Personal carbon rationing, as presented in this thesis, would be a UK-wide allowance system covering carbon emissions generated from fossil fuel energy used by individuals for personal transport, including air travel, and within the home. It would account for around half of current UK carbon equivalent emissions from energy, including international air travel (see section 5.3.4). The primary aim of the scheme would be to deliver guaranteed levels of carbon savings in successive years, reaching the government's current target of 60% reduction by 2050 and interim targets, or whatever alternative targets are deemed necessary as time progresses. It would not cover the energy used by the government and business sector; possible methods of reducing carbon emissions in parallel from these sectors are outlined briefly later.

Personal carbon rationing as a UK solution emerges from the key proposed global solution to climate change: "contraction and convergence", which is described in more detail in section 5.5. Contraction and convergence aims to deliver global carbon savings fairly and with certainty. Personal carbon rationing is based on the same approach to achieving savings, and aims to deliver these benefits of equity and certainty on a UK scale. Carbon rationing is designed as a policy which will enable the UK to make national savings as its contribution within a global agreement on limiting greenhouse gas emissions. It could well be a suitable national response in other countries as well, but it is only applied to the UK in this thesis.

The main features of carbon rationing would be:

- Equal rations for all individuals
- Tradable rations
- Year-on-year reduction of the annual ration, signalled well in advance
- Personal transport and household energy use included
- A mandatory, not voluntary arrangement.

In the following sections the reasons for each of these features of the policy are presented. There is also discussion about each feature and alternative approaches are identified and debated.

Carbon rations could equally well be described as 'allowances', 'entitlements' or 'quotas', but the word 'ration' is used within this thesis for clarity and consistency.

5.3.2 Equal rations

Carbon rationing will be based on equal carbon rations for all adults. Children would probably receive somewhat less than the adult ration; the rationing scheme would have to be fair to children, but not unfairly advantage people with larger families. Equal rations are based on the principle of equity, where equity is defined in an egalitarian way as giving people equal rights to a share of atmospheric space. This is the same principle as that which underlies contraction and convergence. Alternative definitions and interpretations of equity do exist, and these are discussed below and in section 5.5.3, but an equal right to emit is considered here to be the most defensible and manifestly fair way of sharing out the UK's emissions total between individuals. This suggestion of equal rations is probably the most challenging part of the rationing scheme – it varies considerably from a more familiar alternative such as carbon taxation.

There are a number of other possible ways of sharing out the UK's carbon emissions. One alternative would be a 'grandfathering' scheme, where those who emit most now are permitted to continue to do so into the future. While protecting the interests of current high emitters, it would reward high consumption and penalise low consumption. Another possibility would be a scheme based on allocating rations according to differentiated energy 'needs'. This could include making allowances for climate (more emissions rights for those in cold Northern Scotland), geographical location (more emissions rights for rural dwellers who have less access to public transport and are more distant from facilities), efficiency of housing, availability of alternatives to car transport and many other factors. The difficulty of defining needs as opposed to wants will be discussed in Chapter 6. This could be a very complex scheme, with no limits on the number of special cases which could be established. In addition to the disadvantage of its complexity, it also privileges higher carbon lifestyles above those of people who live more carbon thrifty lives. Finally, carbon taxation would provide a completely different approach to sharing out carbon emissions, allowing the rich far more access to fossil fuel energy than the poor. The case for and against carbon taxation is discussed further in Chapter 6.

A scheme based on equal rations can make special allowances for classes of people with special needs, as occurred with food rationing in the second world war (described in Section 5.6.2). However, in the longer term it would be better for the government to subsidise efficiency /

renewable energy measures for certain groups of people rather than grant them extra allowances. The more exceptions that are made, the lower the available ration will be for everyone else. Chapter 6 analyses in detail the effect of equal carbon rations on different income groups, on people in single person households and the effect of living in an older or newer home - to see if any of these groups might be disadvantaged.

A concern for equity is one of the key motives around introducing national carbon rationing based on equal shares. But rationing is not being introduced in order to resolve existing inequities in access to energy services within society. Analysis in Chapter 6 will show it is likely to disadvantage far fewer of the poorest people in society than carbon taxation, but it is not this outcome which is the key argument in its favour.

5.3.3 Tradable rations

Because of differences between individual carbon emissions, the carbon ration necessary to cover current consumption will vary considerably between individuals. Those who invest in household efficiency and renewables, travel less, and who lead lives with a lower energy input, will not need all of their ration and will therefore have a surplus to sell. Those who travel a lot, or who live in large or inefficient homes will need to buy this surplus to permit them to continue with something like their accustomed lifestyle. Thus people will want to trade carbon and trading would be an integral part of a carbon rationing scheme. By incorporating trading within the rationing scheme, economic theory says that savings should be made at least overall cost. The price of ration units would be determined by the availability of the surplus set against the demand for it.

The question arises, does having trading as part of the system undermine its egalitarian credentials? Certainly, in the early years of its introduction, well-off people will be able to buy the surplus from those who lead energy-thrifty lifestyles. But the cost of doing so will rise steadily as the ration is progressively reduced. Nobody would be forced to sell their ration, and if people do choose to sell some of their rations, they will gain financially. So, while it is true that trading allows wealthier people to lead a higher carbon lifestyle if they choose, this does not undermine the basic equality of the rationing system.

5.3.4 The boundaries of personal carbon rations

Personal carbon rations in this thesis cover all household energy use and personal transport energy use including air travel, that is, all direct use of energy by individuals. Personal transport energy use includes all travel undertaken in a personal capacity, including travel between home and work, but not travel undertaken on behalf of an employer or as a necessary part of an individual's occupation.

Figures 5.1 and 5.2 show total carbon emissions including carbon equivalent emissions from international air travel (Chapter 2 explained how these were calculated) for 2001. The year 2001 is the latest for which total UK carbon emissions figures have been published, split into the industrial, domestic, transport and other sectors (DEFRA 2004a).

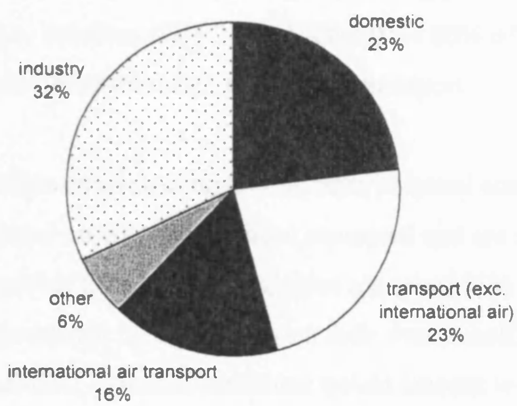

Figure 5.1: Percentage of UK annual carbon equivalent emissions (including international air travel) by sector, 2001

In Figure 5.2 all equivalent emissions from transport have been split into personal and non-personal transport (where 'non-personal' encompasses freight transport and all other business and commercial transport). Official statistics are not split by personal and non-personal travel, however, it has been possible to make estimates of this split, as explained below.

DTI report Department of Transport estimates of the percentages of road fuels (split into motor spirit and derv, i.e. petrol and diesel) which are used by cars and taxis, as opposed to goods vehicles (including light vans) and buses and coaches (DTI 2004a). Combining the energy use by cars with the carbon intensities of petrol and diesel (DEFRA 2001a), shows that 61% of carbon emissions from road travel come from cars. Over 90% of total UK transport energy, excluding that for international air travel, is used in road transport (DTI 2004a). Therefore the simplified assumption is made here that carbon emissions from travel by car are personal transport emissions, and that 61% of all transport emissions, excluding international air travel, are from personal transport. In reality, personal travel also includes travel by bus, coaches and trains and does not include all travel by car, some of which is carried out for business purposes. However, data to carry out a more precise analysis which would, for example, look in more detail at the split of personal and non-personal transport in the non-road modes, as well as the percentage of car miles which are driven for non-personal purposes, are not readily available (Brand 2004). Both because cars are used for the vast majority of personal distance travelled (85% of passenger kilometres in 2003 (DfT 2004b)) and because more detailed analysis is difficult due to lack of data, it is reasonable to make the assumption that personal transport energy use is equal to energy use by cars.

For international air transport from the UK in 2002, only 14% of journeys were undertaken for business purposes, with the remaining 86% of journey trips being personal travel, primarily for holidays and visiting friends or relatives (DfT 2003c). Therefore 86% of carbon equivalent international air emissions have been allocated as personal transport.

Using these assumptions, carbon equivalent emissions from personal and non-personal transport, including international air travel, have been separated and are shown in Figure 5.2. Combining domestic and personal travel emissions, gives a total of 51% of UK carbon equivalent emissions being generated by individuals on their own behalf. (If international air travel emissions were not included, personal emissions would amount to 44% of the total.)

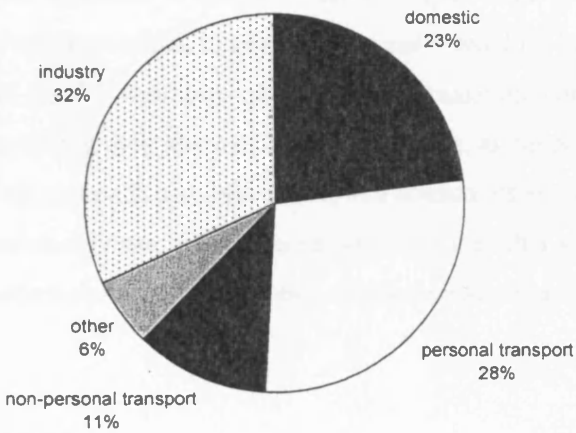

Figure 5.2: Percentage of UK carbon equivalent emissions (including international air travel) by sector – with transport split into personal and non-personal, 2001

The average individual's personal carbon and carbon equivalent emissions are made up of 45% from household energy use, 27% from international air travel, and 28% from all other modes of transport.

There are a number of good reasons for including both personal transport and household carbon emissions in the personal ration. Firstly, as has been demonstrated, by including both, half of the energy-related carbon and carbon equivalent emissions in the UK economy would be covered. Secondly, reducing emissions in the transport sector is unlikely to be any easier than in the residential sector and a mechanism to cap and reduce emissions in this sector will be certainly be required: rationing is just as relevant as for household energy (Hillman & Fawcett 2004). Thirdly, combining personal transport and household energy use in a single scheme would also give people more flexibility in responding to carbon restrictions. In addition, as will be demonstrated in Chapter 6, a household energy emissions only ration would impact most heavily on the least well-off individuals, in a way that a combined ration would not. Finally, dealing with household energy use and personal transport separately would add to complexity for no obvious gain, and so the personal ration should cover both.

The personal carbon ration does not cover the carbon embodied in goods and services, so purchasing, say, mange tout air-freighted from Kenya, which have high associated air miles and carbon emissions, would not involve the purchaser giving up any of their ration. In theory, it might be possible to calculate the 'embodied' carbon in each product or activity (i.e. the carbon used to produce an apple, stereo equipment or car) and give consumers a further allowance to be used when buying products. However, as argued in Fawcett, Hurst, & Boardman (2002) this would be both extremely complex and data-intensive for goods. Embodied carbon rating would require a life-cycle analysis approach, to assess the carbon impact from cradle to grave. It would be even more difficult, if not impossible, to apply to services - would it be possible to carbon rate a haircut or a hospital stay? It would be much simpler to make the non-domestic sector directly responsible for reducing their share of carbon emissions, as suggested by Starkey & Fleming (1999). This is the approach also taken here, that consumers should only be directly responsible for their direct energy use. As carbon emissions in the other sectors would also be controlled, the price structure should alter in favour of low embodied carbon goods and services.

5.3.5 Reducing rations

UK carbon rations will have to decrease over time, in response both to the need to reduce global emissions and to allow for the expected rise in national population. The level of future rations depends on what cuts need to be made to ensure that the agreed level of carbon dioxide emissions in the atmosphere is not exceeded. It also depends to a lesser extent on the date chosen for global convergence on equal emission rights. Rations have been calculated both on the basis of the government's 60% reduction target for 2050 (designed to stabilise concentrations at 550ppmv), and on the basis of the reductions that would be needed to stabilise at 450ppmv by 2030 – which gives a reduction in UK emissions of approximately 80% by 2050 (GCI 2004).

Table 5.1 shows actual values for annual carbon emissions and population for 2000 and 2002 with projections to 2050. Projected emissions are based on a combination of national emissions projections by the Department of Trade and Industry (DTI 2000) and the government's estimate that carbon emissions from aircraft can be expected to double by 2020 (DTI 2003b) and using a factor of 3 for transforming carbon emissions into carbon equivalent (as explained in Chapter 2). Carbon emissions projections are only available to 2020. Chapter 3 has already discussed the weaknesses of the DTI projections. However, this gives some idea of how personal carbon emissions might change up to 2020 in the absence of carbon rations.

In order to calculate future personal carbon emissions and rations, personal emissions are estimated to remain at 50% of the total UK carbon equivalent emissions up to 2050 (based on the 51% figure calculated earlier). Population projections used to calculate the per capita figures come from 2002-based figures (Shaw 2004). The targets for 60% or 80% reduction are based on 60% or 80% of UK carbon equivalent emissions in 2000 for personal energy use.

Table 5.1: Estimated UK carbon rations for personal energy use per capita to 2050 under different reduction scenarios

Year	Carbon emissions MtC/yr	International air carbon equivalent emissions MtCe	Population (million)	Future personal carbon emissions / rations per person (tCe/year)		
				Business as usual	60% reduction by 2050	80% reduction by 2050
2000	**152.6**	**32.1**				
2002	**150.4**	**28.8**	**59.229**	**1.51**		
2005	145.8	34.7	59.802	1.51		
2010	148.1	44.5	60.808	1.58	1.58	1.58
2020	156.3	64.2	63.026	1.75	1.33	1.26
2030	No CO2 projections are available after 2020		64.835		1.07	0.93
2040			65.402		0.82	0.61
2050			65.440		0.56	0.28

Sources: Shaw 2004, DTI 2000, RCEP 2000

Figures in bold are actual values, all the remainder are projections

As with global carbon reductions based on contraction and convergence, rationing would be introduced in a phased way, so that average per capita emissions fall gradually. Future projections for carbon rations are based on linear projections of reduction between 2010 and 2050 (see section 5.7.2 for explanation of start date of 2010). The figures in Table 5.1 also assume that adults and children get equal personal carbon rations, although in operation children would probably be allocated a lower ration. However, as children under 16 comprise only 20% of the population (Rickards et al. 2004), giving them a lower ration would not enable the adult ration to be increased by very much. All these assumptions are simplifications, and many variations can be imagined. For example, in reality annual reductions in carbon rations might be lower at first as people got used to the scheme, and increase over time as society became better oriented towards low carbon living.

These proposed carbon reductions will have real consequences, particularly for international air travel. Under the 60% reduction scenario, just one return flight from London to New York (using current technology) would exceed the whole personal carbon ration for the year by 2040, and in the 80% scenario by 2030. As noted in Chapter 1, stabilising carbon dioxide concentrations — at any level — requires the eventual reduction of global carbon dioxide emissions to a fraction of their current levels. So, under both scenarios, carbon rations will have to continue to fall from 2050 into the future.

5.3.6 Mandatory

In order to be effective, carbon rationing would have to be mandatory. A voluntary approach would not succeed: the 'free-rider' would have far too much to gain. As environmental thinker Michael Jacobs has written:

"...environmentally sustainable consumption will not come about through individual choices, but through regulatory policies collectively decided and imposed through the state. ... Admirable as voluntary reductions in consumption are, they are not the route to environmental improvement."(1997:52)

When the wider public interest is at risk and the issue one of critical importance to the welfare of the community, government intervention is necessary (Hillman & Fawcett 2004).

5.3.7 The key benefits of personal carbon rations

One of the key benefits of carbon rationing is that it provides a framework for assured carbon reductions. No longer might it be necessary to have separate government policies and programmes to promote everything from cycling strategies to efficient refrigerators. Under carbon rationing, the carbon 'market' should recognise the benefits of renewable energy, household insulation and low carbon methods of transport. Many people may choose to meet all their carbon reductions through technical improvements as in Johnston's DJ-DS scenario. But without carbon rationing there would be no mechanism for ensuring that they did so. The great advantage of carbon rationing is that it allows people to reduce their emissions in the way that suits them best, whether through technical efficiency improvements and using more renewable energy or through demanding fewer energy services, or any combination of these strategies.

The government might still wish to have some long-term research programmes and other policies to provide solutions which cannot emerge from market forces (whether conventional money-based market, or the new carbon market). However, since the environmental damage caused by energy related decisions will finally be fully recognised, there should be less need for intervention to try and correct for the market imperfections that currently exist.

5.4 Literature review

Relatively little has been written on the subject of carbon rationing or personal carbon allowances. These are fairly new ideas which have not yet been widely or fully explored. This section brings together the limited literature on carbon rations and similar schemes which go by various names such as 'domestic tradable quotas' and 'permit trading'.

5.4.1 Carbon rationing

The most prominent UK proponent of carbon rationing is Mayer Hillman. He has been developing and promoting the idea of personal carbon rations for many years (e.g Carley, Christie, & Hillman 1991). Hillman's arguments in favour of carbon rationing arise from a concern about the urgency of climate change and a belief in equity as the only feasible principle on which to base a society-wide agreement on carbon reductions (Hillman 1998). A full description of his arguments for carbon rationing and details of the proposed scheme are given in Hillman & Fawcett (2004). This is the same in all important respects as the scheme described in this thesis, and is very similar to a description of carbon rationing developed by the author independently of Hillman (Fawcett 2003).

5.4.2 Domestic tradable quotas

A detailed approach to carbon saving across the whole economy has been developed by Starkey & Fleming (1999). Their proposal is called 'Domestic Tradable Quotas' (DTQs) – where domestic indicates a national as opposed to an international scheme. The basis of the policy is that the national government sets an overall carbon budget that is reduced over time. The 'carbon units' making up this budget are issued to adults and organisations. All adults receive an equal and unconditional entitlement of carbon units; organisations acquire the units they need from a tender, a form of auction modelled on the issue of government debt. There is a national market in carbon units in which low users can sell their surplus and higher users can buy more. Virtually all transactions could be carried out electronically, using the technologies and systems already in place for direct debit systems and credit cards. Starkey and Fleming claim that the scheme would be effective, equitable and efficient.

DTQs have been designed to meet the twin objectives of a reduction in carbon emissions and economic efficiency. The policy would allow government to take control over the rate at which fossil fuel consumption is reduced, while allocating the available resource fairly and maintaining price flexibility so that the economy can distribute it efficiently. In addition, the system would provide the framework for establishing carbon reduction as a proper objective of public policy, playing a central part in aligning social norms and values with individual responsibility for reducing carbon emissions. It would complement at national level the international contraction and convergence model for sharing carbon emission rights.

This work is being developed further under the Tyndall Centre 'Decarbonising modern societies' programme by Anderson and Starkey (2004). Future work in the research programme includes: assessing the equity of allocating emissions rights under DTQs and alternatives; assessing the technological feasibility of introducing DTQs; assessing the likely efficiency of DTQs and other instruments in reducing greenhouse gas emissions from energy use, and; assessing the public acceptability of DTQs via focus groups. Anderson and Starkey's work appears to be the only research currently being funded in the UK which looks at carbon rationing type schemes.

This work has attracted some political attention, with Colin Challen MP hosting a meeting to discuss DTQs at the House of Commons in Spring 2004. Following this, on 6th July 2004 he introduced a private member's bill on "Domestic tradable quotas (carbon emissions)". The aim of the bill was to introduce a national trading scheme for carbon emissions and to set a national ceiling for carbon emissions (Hansard 2004). The bill was scheduled for a second reading in October 2004, however it has subsequently been dropped.

5.4.3 National permit-trading

Dutch researchers Woerdman, Boom, & Nentjes (2002) have also discussed the idea of a national permit-trading scheme which could include householders and motorists. Woerdman also explored similar ideas briefly in an earlier paper (Woerdman 2000). The authors distinguish between downstream and upstream trading systems. In a downstream trading system both large and small energy end-users, including households and motorists, receive tradable permits. In an upstream trading system, permits are allocated to producers and importers of fossil fuels, who pass on their permit costs in a mark-up on the fuel price to their customers. They suggest that 'permit trading' could be both effective and efficient because it places a ceiling on total emissions and attaches a price to the entitlement to emit, providing a strong incentive to switch to sustainable energy. Woerdman et al argue argue that a downstream system which directly incorporates firms as well as households and motorists can be administratively feasible and cheap, contrary to the commonly held opposite view, thereby enhancing its potential acceptability. Woerdman et al appear to see permit trading as primarily an economic instrument, rather than a means of fairly sharing the available carbon emissions.

5.4.4 Average utility carbon per household

A scheme which could be characterised as offering collective responsibility based on personal carbon rations was suggested by Fawcett, Lane, & Boardman (2000). This scheme was called Average Utility Carbon per Household, or AUCH. The national government would set sector targets for carbon reductions and, based on this, would give energy utilities a reducing cap for emissions. Initial allocation of emissions permits to the utilities would be based on the number of customers, with separate allocation for gas and electricity use. The idea was that utilities could achieve lower average household emissions through investment in both lower carbon technologies (including renewable energy) and in reducing demand per household. Energy utilities were seen as a key actor, who already have some responsibility to save energy via existing UK legislation (via the EEC scheme, as explained in Chapter 2), and who have the technical knowledge and capability of investing to achieve carbon savings.

AUCH is based on the same principle as DTQs and carbon rationing – that of equal emission allowances for individuals which reduce over time – but the location of responsibility for meeting the rationing targets is allocated to a different actor. The thinking behind AUCH emerged from research which demonstrated the limits individuals face in trying to reduce their emissions:

"*In reality, consumers have restricted incomes and fuel choices, imperfect information, face limited choices in the retail environment, have to rely on the advice of professionals and, not unreasonably, have priorities other than energy and carbon efficiency. Consumers are people – bound into complex webs of social and cultural expectations that influence what is considered desirable, acceptable and normal.*" (Fawcett, Lane, & Boardman 2000:53).

In their Carbon UK report, Fawcett, Hurst, & Boardman (2002) discuss carbon management throughout the economy at different levels by different actors. For household energy, the AUCH concept introduced in ECI's earlier work is recommended. However, for transport there is discussion of personal carbon allowances for motorists. For airline emissions two possibilities are discussed: caps on emissions for airline companies or individual carbon emissions – carbon air miles. However, a comprehensive carbon rationing scheme was not considered.

5.4.5 Other similar ideas

Household carbon rations, allowances or tradable permits are far from being mainstream ideas, however, there have been references to similar ideas. In an article for an Environment Agency magazine about a fictional family in 2020, Boyle (2003) mentions 'a domestic greenhouse gas allowance'. The ideas are also beginning to be taken up in other research. For example, the applicability of DTQs has been considered in a study of environmental taxes and their effects on lower income households (Ekins & Dresner 2004). The results of this study are discussed in Chapter 6.

5.4.6 Summary and comparison

The differences between the proposals examined are chiefly in terms of their scale, i.e. how many sectors of the economy they cover, and where responsibility for making carbon reductions lies – as summarised in Table 5.2. They are all based around the idea of equal allowances for individuals and, apart from AUCH, include notions of trading of allowances.

Table 5.2: Comparison of carbon rationing-like proposals

Version of idea	Energy covered	Responsibility
Carbon rations	Personal transport and household energy	Individual
DTQs, Permit trading	All energy - with personal allowances for household and transport energy. DTQs would not include air travel in personal allowances.	Individual for personal consumption.
AUCH	Household energy	Energy company

The remainder of this chapter builds on the existing literature and develops the idea of carbon rationing.

5.5 The international context for carbon saving

5.5.1 Introduction

The arguments for carbon rationing at a national level follow directly from consideration about how carbon reductions should be achieved internationally. As explained in Chapter 1, the Kyoto agreement was only intended to be the first of successive global agreements on reducing the threat of additional climate change. Kyoto itself has turned out to be something of a disappointment, with very modest savings targets and the USA remaining outside the agreement. If greenhouse gas emissions are to be controlled world-wide, an effective successor to the Kyoto agreement is vital. This section looks at 'contraction and convergence' and alternative approaches to post-Kyoto carbon reductions. There is also a discussion of the meaning of equity in global carbon negotiations, as agreeing a common definition of equity will be key.

5.5.2 The current position

Before discussing the future of international carbon emissions, it is important to understand in a little more detail the current international picture on emissions. As mentioned briefly in Chapter

2, current global per capita carbon emissions are highly unequal. Table 5.3 shows per capita carbon dioxide emissions from fossil fuel burning, cement manufacture and gas flaring for a selection of countries. Each Briton emits about two and a half times the global average carbon emissions from fossil fuels, and the average American emits 500 times as much the average person in Afghanistan. Note that these statistics do not include carbon emissions from land use change, including those from unsustainable use of forests, which also vary considerably by country. Neither are they adjusted to include the full global warming effect of carbon emissions from air travel.

Table 5.3: Per capita carbon dioxide emissions from fossil fuels, various countries, 2000

Country	Emissions per capita, tC
USA	5.40
Australia	4.91
UK	2.59
France	1.68
Mexico	1.19
China	0.60
India	0.29
Bangladesh	0.06
Afghanistan	0.01
Global average	1.09

Source: Marland, Boden, & Andres 2003

This data also indicates that there is considerable potential for the UK individuals to increase per capita emissions. The UK is by no means at the top of the international league.

5.5.3 Equity

Equity issues are central to the international climate change debate. This is for both principled and practical reasons. Inter-generational equity is at the heart of policy on reducing greenhouse gas emissions because, as the emissions accumulate in the atmosphere for hundreds of years, today's emissions place a burden on future generations. Equity is explicitly acknowledged as an important consideration in the Framework Convention on Climate Change (FCCC). Article 3.1 of the FCCC states that parties to the convention should 'protect the climate system for the benefit of present and future generation of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities' (United Nations 1992). Equity is key for practical reasons as well. It is widely agreed that without equity, transparent in its application, there can be no realistic prospect of public acceptance or political agreement to introduce the measures needed (IEA 2002a).

However, there is more than one definition of equity. More than a dozen different equity rules are defined and have been extensively discussed in the literature (IPCC 2001c). These range from egalitarian rules (where equal rights are assigned on a per capita basis), to sovereignty rules (where allocation is to governments), to ability to pay rules (varying according to national well-being), to polluter pays (where abatement costs are distributed in proportion to emission levels), to utilitarian rules (where the goal is the greatest happiness for the greatest number), to procedural equity (related to how a decision is made) (IEA 2002a).

Deciding which definition of equity to adopt is crucial to answering practical questions such as who is allowed to suffer how much climate change damage, and who gets to emit how much carbon. Three different interpretations of equity - equal rights, ability to pay and polluter pays - would result in different allocations of responsibility for achieving carbon reductions. Indeed, 'ability to pay' and 'polluter pays' would require a regular re-allocation of responsibility over time as countries' wealth and emissions changed. 'Polluter pays' could encompass either current or cumulative historic emissions - the choice of which would make a huge difference to the UK which has been responsible for 15% of cumulative global emissions since 1750, but is responsible for just over 2% of current emissions (Marland, Boden, & Andres 2003). This thesis concurs with the argument of the Global Commons Institute (Meyer 2000) that the equal rights interpretation of equity is the most morally defensible option and the only one likely to lead a successful global carbon control agreement. Therefore, the definition of equity which is used here is that of equal rights to use the atmosphere.

5.5.4 Contraction and convergence

Contraction and convergence (C&C) principles were first proposed by the Global Commons Institute in 1990 (Meyer 2000) as a means of reaching a just global agreement on emission reductions. C&C is founded on two fundamental principles: first, that the global emission of greenhouse gases must be progressively reduced; secondly, that global governance must be based on justice and fairness.

C&C consists of:

Contraction: An international agreement is reached on how much further the concentration of CO_2 in the atmosphere can be allowed to rise before the changes in the climate it produces will become totally unacceptable. Once this limit has been agreed, it is possible to work out how quickly current global emissions must be cut back to reach this target. This cutting back is the contraction part of contraction and convergence.

Convergence: Global convergence to equal per capita shares of this contraction, by an agreed year.

C&C does not entail a particular concentration of greenhouse gases as being the safe limit, nor a time scale for reductions – this would be a matter for scientific judgement and political negotiation. Global emissions trading would be included within C&C to ease transition costs towards lower emissions lifestyles and techniques. Those countries which were unable to live within their allocation would be able to buy more permits from countries which ran their economies in a more energy-frugal way. This feature would lead to a steady flow of purchasing power from countries that have used fossil energy to become rich to those still struggling to break out of poverty.

The lower C&C graph (Figure 5.3) shows how fossil fuel-related carbon emissions have evolved over time for six blocks of countries: the USA; the former Soviet Union (FSU); OECD countries excluding the USA (which includes all the EU and other European nations, Australia, New Zealand, Japan and Canada); India; China; and the rest of the world. Not surprisingly, most of the historic carbon emissions, prior to 2000, are the responsibility of the developed world.

The graphs show the effect from 2000 onward of introducing a maximum concentration target of 450ppm with convergence by 2030. The lower graph shows the effects on country blocks, the upper one on individuals within those blocks. The highest carbon emitting countries have to make the largest contributions to the overall reduction in emissions, so the change per capita required is greatest for the United States, followed by other OECD countries including the UK. Emissions from developing countries would be permitted to increase to 2030 under this particular scenario. Thereafter, as for the developed countries, their emission allowances would gradually reduce over time to ensure that the 450ppmv target was not breached. The graphs assume that there is no trading between countries; in reality, the pattern of emissions might be rather different from this, with rich countries emitting more, having paid the poorer countries for the privilege of doing so.

This is just one illustration of the contraction target and convergence dates which might be chosen. An earlier convergence date would disadvantage developed countries who would have to bring their emissions down more quickly to the agreed target, and conversely would benefit developing countries who would get emissions allowances in excess of their actual emissions. A later convergence date would benefit developed countries - allowing them to continue their higher emissions for longer. However, it would also mean that the per capita convergence target would have to be lower for everyone, because more carbon will have been emitted prior to convergence. The national interests of developed and developing countries will tend to lead to different views about the ideal date for convergence.

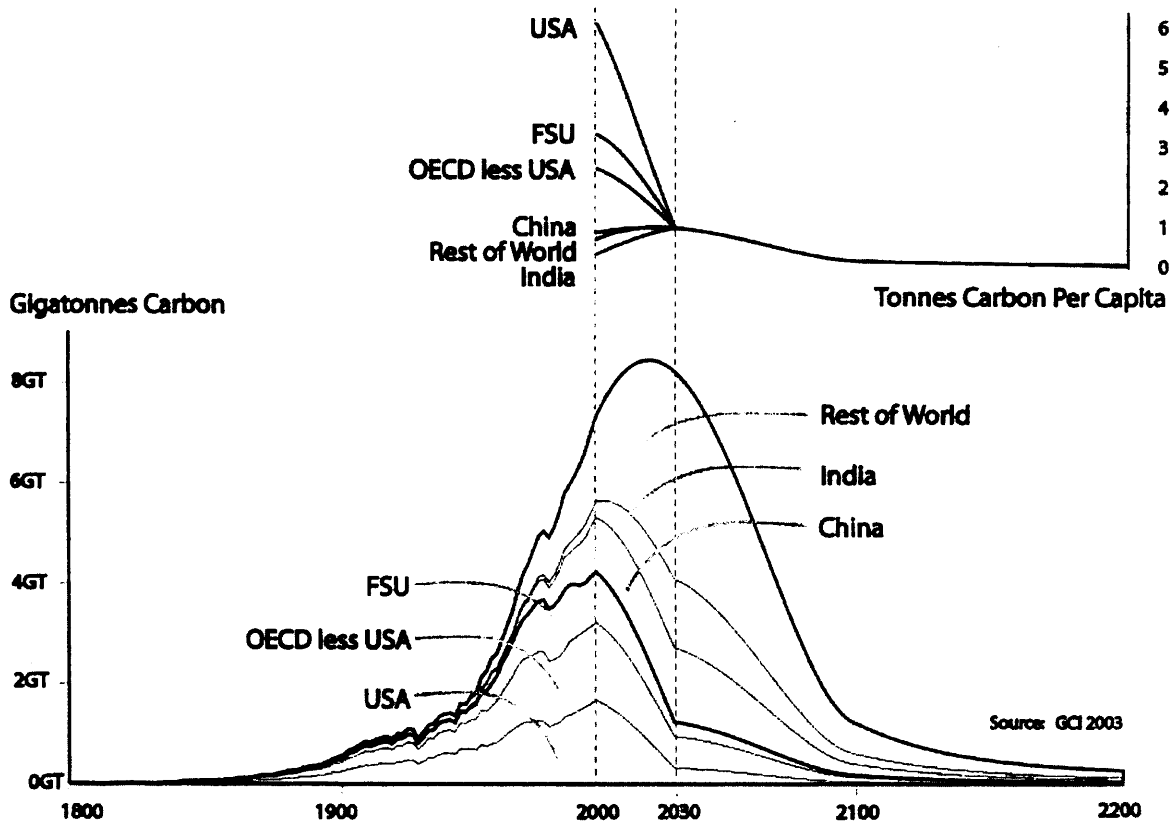

Figure 5.3: Historical and future carbon emissions under C&C (shown gross and per capita) for a maximum of 450ppmv atmospheric concentration achieved by 2100, with per capita emissions converging to equality achieved by 2030

Source: GCI 2004

C&C is considered by many to be the scheme which should succeed the current Kyoto agreement. It has many influential supporters, including the UN Environment Programme and the European Parliament (Pearce 2002) and is being seen by many as the only realistic basis for a future agreement (Anon 2003). Houghton (2004) has said that: *"Its simple and appealing logic means that it is a strong candidate for providing a long-term solution"*. The Royal Commission on Environmental Pollution has recommended that the UK should adopt a target for carbon dioxide emissions reduction of 60% from 1997 levels by 2050. This is based C&C principles with the aim of ensuring that an upper limit of 550ppm carbon dioxide in the atmosphere is not exceeded (RCEP 2000). However, C&C has not yet been adopted as the post-Kyoto negotiating position of any of the Annex 1 countries. This includes the UK, despite the government having accepted the RCEP's C&C-based argument about targets for 2050.

5.5.5 Other post-Kyoto frameworks

The UK government, while it has so far refused to endorse C&C, has not identified its preferred post-Kyoto framework. Neither is there a leading alternative which other countries are joining in supporting. A review of proposals for tackling climate change published by the New Economics Foundation identified two main alternatives to C&C: the 'Brazilian' and the 'Kyoto plus' proposals (Evans 2002).

The Brazilian proposal emphasises responsibility for the historic emissions that have caused the rise of atmospheric concentrations, temperature and damage. In this, countries with a longer history of industrial development would bear a greater share of responsibility than those with shorter histories. Thus, with this greater share, the UK would face a huge 63% reduction by 2010 against 1990 levels whilst Japan's reduction would be less than 10%. The very large reduction required of the UK reflects its historic responsibility for 17.5 % of global emissions from fossil fuels (since 1750), compared with Japan's responsibility for just 3.9% over the same period. This puts all the responsibility for emissions reduction on the older developed countries, excludes developing countries from quantified commitments and has no formal concentration target. The fact that some countries would have no commitments would make it unacceptable to the USA, in particular, because it is not prepared to be the signatory of any international agreement on climate change which does not involve a commitment from these other countries (Meyer 2000).

By contrast, as its name implies, the 'Kyoto plus' proposals are variations on the theme of continuing the existing approach. However, they lack a target for carbon concentrations in the atmosphere and a clear idea of where the process ought to be going. There is no leading variation on the 'Kyoto plus' theme.

There are a number of other complex allocation systems which have been proposed with a mix of concerns about equity, economic efficiency and transitional arrangements for developed and developing countries (IEA 2002a). The more complex the system the less likely it is that global negotiations could ever be concluded on such a basis, where negotiations around different elements of the allocation system could continue ad infinitum.

Evans (2002) concluded that the GCI's C&C strategy is the only framework which offers assurance of first, arriving at a defined atmospheric concentration, second, the equitable allocations that developing countries have very rightly stated to be an essential part of any agreement, and, third, the potential for immediate implementation. None of the alternatives, including the two above, can offer all of these vital features. In summary, C&C is the only framework for future negotiations which includes all the countries of the world on an equitable basis and offers a mechanism for guaranteeing reductions in carbon emissions.

5.5.6 Previous international environmental agreements

There has been no previous environmental problem on the scale of climate change. However, amongst other global environmental issues, such as deforestation, soil erosion and acid rain, the most similar problem is the hole in the ozone layer. Like climate change, most nations were contributing to varying degrees to the problem of depletion of the ozone layer, and widespread agreement was needed to reduce the production of ozone depleting chemicals. Ozone depletion was causing a current problem, but the more serious threat was that emissions would accumulate into the future and cause greater damage, as is the case for greenhouse gas emissions. The problem of ozone depletion and the solution which was devised are described briefly here, and this is followed by consideration of the lessons that can be learned for climate negotiations.

In the mid-1970s atmospheric chemists discovered that chlorofluorocarbons (CFCs), although inert in the lower atmosphere, are highly destructive of ozone once they make their way into the upper atmosphere layer known as the stratosphere. This was of concern because damage to the ozone layer allows additional high energy radiation to reach the earth's surface, which can harm human health and the wider ecosystem. Although some governments took immediate action in the late 1970s to limit CFC use as propellants in spray cans, others contended that there was no scientific proof about the destructive nature of CFCs (Glantz 2003).

A sharp thinning, or 'hole', in the ozone layer over the Antarctic was brought to wide attention by scientists from the British Antarctic Survey in 1985 (Houghton 1997). The extent of destruction of ozone and the fact that it was occurring over polar regions was unexpected, given the incomplete state of scientific understanding of stratospheric chemistry (Christie 2001). Subsequently, scientists showed that the hole was caused by man-made ozone depleting chemicals (ODCs) including CFCs which catalyse the destruction of ozone during the spring over Antarctica and to a lesser extent over the Arctic. Following this, political action to reduce CFC manufacture, use and trading was reinforced if not accelerated (Glantz 2003).

In 1987 the Montreal Protocol on Substances that Deplete the Ozone Layer was agreed and signed by 24 industrialised countries and the EU. The protocol set out the time schedule to freeze and reduce consumption of ODCs and required all parties (i.e. signatories) to ban exports and imports of controlled substances to and from non-parties. At subsequent meetings, timetables to freeze and phase out ODCs were brought forward as scientific knowledge of the problem increased. Developing nations have subsequently signed up to the protocol, which has now been ratified by 183 countries. Use of CFCs was phased out in the developed countries by the end of 1995 and will be phased out in developing countries by 2010 (UNDP 2004). According to the Environment Agency (2004), the ozone layer may recover by around 2050, but alteration of the atmosphere by greenhouse gases and changing global temperatures make the nature of recovery uncertain.

The most positive lesson from the ozone experience is that it proved possible to have an international environmental agreement which largely succeeded in limiting further damage. As Houghton (2004:323) suggests, the response to the hole in the ozone layer means *"A way forward for addressing global environmental problems has .. been charted."* There are a number of interesting precedents set by the Montreal Protocol and its successor agreements:

- different timetables for freezing and phasing out production and use of ODCs were agreed for developed and developing countries, with developed countries taking the lead. The differential timetables were agreed in recognition of the need of developing countries for industrial development and their relatively small production and use of ODCs (UNDP 2004);
- there were sanctions for non-compliance. Without the trade sanctions, there would have been economic incentives for non-signatories to increase production, damaging the competitiveness of the industries in the signatory nations as well as decreasing the search for less damaging CFC alternatives;
- reductions in ODC production and use increased over time as scientific evidence showed more action was needed;
- action was taken in the absence of statistical evidence of impacts on human health (Glantz 2003).

The different responsibilities of developed and developing countries in the ODC case are similar in effect to what would happen under a contraction and convergence framework. Although all countries would be working towards the same convergence date, in terms of absolute emissions, developed countries would make bigger reductions than developing ones. Trade sanctions would be equally required in a C&C framework, as 'free riders' and cheats would have a lot to gain.

It is encouraging that action was stepped up as the seriousness of the problem was increasingly understood – something that is badly needed in response to the increasingly serious news about climate change outlined in Chapter 1. Equally striking is the fact that action was taken well in advance of proof of actual, rather than potential, damage to human health. By contrast, it is already clear that extreme events, which are almost certainly a result of climate change, are damaging human health, e.g. the heat wave in Europe in 2003.

This comparison between the ozone hole problem and climate change is not to deny that the causes of climate change are much more complex and fundamental to the world's economy than the use of the niche market chemicals which caused ozone destruction. For example, since 1991 the Multilateral Fund for the Implementation of the Montreal Protocol has spent $1.6 billion on aiding phase out of consumption and production of ozone-depleting substances in developing countries (Multilateral Fund 2004). Although the cost of reducing greenhouse gas emissions is disputed, and estimates produced by different models differ for many reasons (IPCC 2001b), it is clear that far greater investment than this will be required. Technical responses and finding alternatives to ODCs were key to their being phased out. There is no simple technical fix available to make the reduction of fossil fuel usage similarly straightforward.

5.6 Experience of rationing in the UK

5.6.1 Introduction

There has been no UK experience of widespread fuel rationing in the domestic sector. The most important example of a mass rationing scheme is food rationing during and after the second world war. Food rationing was a radical policy introduced for reasons of equity in the face of a national emergency, and thus it has some characteristics in common with carbon rationing. The considerations and debates about this policy should be able to tell us something about the issues that carbon rationing would raise. In addition, policies currently in place for energy use and carbon rationing in the non-domestic sector have some similarities to a rationing scheme. Both of these experiences are described, and the similarities between these schemes and carbon rationing are analysed.

During the second world war in the UK access to both coal and petrol was restricted for householders, but neither of these schemes had a great effect on the population. Coal was the main heating fuel for households of the period. Restrictions were introduced on coal deliveries in 1941, but a full rationing scheme was never introduced. This was for several reasons including public resistance to fuel rationing and controversy about the fairness of the proposed scheme, government concern that it might not be possible to deliver a guaranteed coal ration if problems of production and transport arose, and the administrative complexity which would have been involved in a system of fuel rationing. The restrictions on coal delivery do not appear to have been very onerous; following their introduction consumption of household coal actually increased (Hancock & Gowing 1949). No restrictions were introduced on the use of gas (at that time town gas) and electricity, instead people were encouraged to be economical with energy. Petrol for private motorists was rationed from 1939 and withdrawn altogether from 1942 (The second world war experience centre 2004). Because there were very few motorists at the time, it was not a restriction which had wide effect.

5.6.2 Food rationing during the second world war

During the second world war years, some degree of food control and rationing operated in almost every country in the world, from the richest agricultural countries like the USA and Australia to the poorest such as India and China (Burnett 1989). In this section the British experience of food rationing is briefly described.

In the course of the war, civilian consumption of food, clothing and miscellaneous goods was reduced drastically as economic resources were directed towards the war effort. The food rationing schemes were concerned mainly with protein foods, milk and fats, the need for which varies less between different sections of the population than it does for other nutritive elements. The British scheme rationed meat, bacon, cheese, fats, sugar and preserves in fixed quantities per head. The principle of a flat-rate ration for all, which ignored the diverse needs of heavy workers at one extreme and small children at the other, was justifiable since only a fraction of all foodstuffs was rationed. In addition, it was recognised that certain categories of the population had special nutritional requirements, and therefore other schemes were super-imposed on this common basis. For example, there were schemes which provided additional proteins, vitamins and minerals to children of pre-school age, nursing and pregnant mothers (Burnett 1989).

Rationing, coupled with subsidies and price controls, promoted greater social equality, and consumption became more equal in contrast with the intense inequalities that existed previously. The fair shares policy was critical in maintaining morale at a time when the share of personal consumption in national expenditure fell from about four-fifths in 1938 to about half in 1944 while resources devoted to the war effort increased from 7 per cent to half the total (Zweiniger-Bargielowska 2000). Despite difficulties, contemporary opinion polls showed that rationing and food control were on the whole popular and discontent was eclipsed by general satisfaction. Ultimately food morale was maintained during the war because people accepted the necessity of sacrifice for the duration, even though two-thirds thought that food quality was worse in 1944 than before the war (Zweiniger-Bargielowska 2000).

The British experience with food rationing is that the chosen scheme was seen as fair and retained public support up to and beyond the end of the war. It was effective: overall nutrition was improved from the period before the scheme started. Rationing operated alongside policies on price control, which ensured that people could afford to buy their ration of food. There were also large-scale governmental persuasion and information campaigns explaining the reason for rationing and advising people on how to cope on their rations.

5.6.3 Non-domestic energy use

The UK has introduced a voluntary carbon trading scheme for business, and a mandatory scheme which will supersede it is being introduced EU-wide from 2005. There has been criticism that the voluntary UK scheme was unlikely to result in real carbon savings (Environment Daily 2003). The EU Emissions Trading Scheme (EU ETS) will establish the world's largest ever market in emissions. Up to 2000 UK installations that collectively emit about half of the economy's carbon dioxide emissions are set to participate in this market. The EU ETS is supposed to provide clear incentives for investment in energy efficiency and cleaner technologies at lowest cost (DTI 2004d). Emissions allowances have been allocated in two stages - first to each of the industry sectors covered by the scheme, then to each installation in that sector on the basis of its previous historical record of emissions. A cap on CO_2 emissions has been set for each installation and allowances issued which are equal to that cap. The allocation of allowances to existing operators who register is free. Companies will be able to trade emissions. The price of carbon allowances will depend on the Europe wide carbon trading market, which will be created by the scheme. Whether the EU ETS results in significant savings depends on details of the scheme. There are concerns that EU ETS will not result in significant savings within the UK (Mitchell & Woodman 2004) or within EU as a whole (ENDS 2004d). It is not yet clear how much EU ETS will deliver in practice.

5.6.4 Comparisons with carbon rationing

Food rationing

Food and carbon rationing are similar in some ways, but also differ in important aspects. The most obvious similarity is the centrality of access to food and energy (resulting in carbon emissions) to British life. Both are vital resources required by everyone and ensuring adequate access to them is important to government and society. Concern for adequate access to energy and reduction of fuel poverty has become an important aspect of government energy policy (DTI 2003b).

However, there are very important differences between carbon rationing and food rationing. Firstly, there is a vast difference in the visibility and urgency of the problems which would be caused in their absence. The reason for introducing food rationing was to ensure the population remained well-fed at a time of national crisis and restricted food supplies. If society had not accepted rationing, and associated price controls, the effect would probably have been very many people going hungry – an unacceptable outcome, and one which would have been immediately experienced by the population. In the case of climate change, no such immediate and personal effects of increasing carbon emissions would be felt. So the motivation for the UK undertaking carbon rationing as a whole is different, and the personal connection with the benefits of carbon rationing would be less immediate.

Another contrast is that food rationing was limited in time, although people did not know how long that time would be. Restrictions on carbon emissions to the atmosphere need to be permanent.

There is a simpler relation between rations and needs for food than there is for carbon rationing. Food rationing is in theory equitable in that each person (of a particular age / gender / activity level) needs about the same amount of food to stay healthy. This is not the case for carbon emissions from household energy: depending on the number of people living together and the efficiency of their home and equipment, similar people can require very varied amounts of energy. Having said that, inequities were recognised as existing in the food rationing system, even after the additional allowances given to special groups:
"To some extent 'rationing bore most heavily on those living alone [and] least upon those families whose capacity for mutual adjustment was greatest'. However, the situation was complicated by the fact that single people frequently had more money to spend on unrationed foods and, whereas the system advantaged families with young children, flat-rate rations were not generous with regard to adolescent needs" (Zweiniger-Bargielowska 2000:79)
Despite these problems, as already stated, the system was generally regarded as fair.

Practically, administration of carbon rationing should be simpler than for food rationing as there are few sellers of gas and electricity and other fuels compared with the tens of thousands of food retailers there were in the 1940s (see following sections). There should be little room for a black market to develop given that flows of fossil fuels are already very well recorded and tightly regulated in our economy. As with the food ration, some sources of energy would be 'off ration'. For example, green electricity, household level photo-voltaics (PV), solar water heating and wood burning stoves would be carbon emissions-free energy.

Finally, carbon would be rationed to prevent further climate change, not because fossil fuel sources of carbon are in any danger of running out. Total carbon dioxide emissions from fossil fuel use since 1750 are estimated at 280 GtC (Marland, Boden, & Andres 2003). Total reserves on earth of coal, oil and gas (including those not yet discovered) are estimated to amount to 5000 GtC (Kasting 2001). Therefore stocks of fossil fuel have the potential to emit about eighteen times more carbon dioxide than has been emitted over the past 250 years. This is completely different from food rationing, which was introduced because of reduced access to food in the UK.

There are many differences between food and carbon rationing, some of which will make it harder to make the case for carbon rationing than it was for food rationing. The key difference is the lack of connection between individual action and the long-term effects on the climate in the case of carbon rationing. A sense of urgency is clearly not present with regard to climate change, despite the evidence that people should be deeply alarmed (as summarised in Chapter 1). In some ways, carbon rationing would be less prescriptive and intrusive in everyday life than food rationing, as people could select from many lifestyle and technical adjustments in order to reduce their personal carbon emissions (as discussed in Chapter 4). Having said that, fossil fuel energy use underpins most aspects of modern life, including growing and importing food, making the transition to a lower carbon society an immense task - but one which must be undertaken whether or not carbon rationing is introduced.

EU ETS

Because EU ETS applies to businesses rather individuals, a lot of the focus to date has been on different businesses and sectors receiving 'fair' emissions allocations. This rather fraught process would not be required when introducing personal carbon rations. EU ETS is a multi-country scheme, which greatly increases complexity. Personal carbon rations would operate within one country, and it is hard to imagine any net benefit from doing otherwise. So, in two important respects, personal carbon rations should be simpler to agree and implement than EU ETS. Maybe the fact that an EU-wide trading scheme has been introduced should offer hope that the challenges of administration and management of a personal carbon rations scheme could be met.

5.7 Carbon rationing as a practical policy

Here some of the practical aspects of introducing carbon rationing are discussed. Many social, technical and policy innovations would be needed to make it easier for people to live within their carbon rations - some ideas about what these might be are outlined. The purpose of this section is to demonstrate how carbon rationing could work within a supportive policy context.

5.7.1 Administration

Administration of carbon rationing should be straightforward. Each person would get an electronic card containing that year's carbon credits – illustrated in Figure 5.4. The card would have to be presented on purchase of energy or travel services, and the correct amount of carbon would be deducted. The technologies and systems already in place for direct debit systems and credit cards could be used. The technical feasibility of managing carbon allowances electronically is discussed in greater detail for DTQs , and is being researched further by Anderson and Starkey (2004).

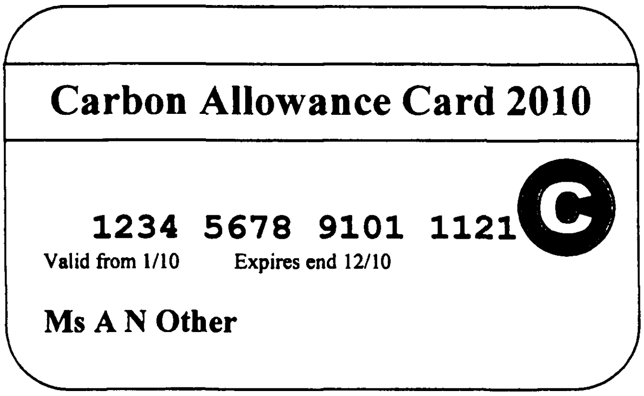

Figure 5.4: Illustration of a possible future carbon allowance card

There are relatively few sellers of gas, electricity, petrol, diesel and other fuels, and flows of fossil fuels are already very well recorded and tightly regulated in the economy. For example, three large suppliers accounted for 82% of gas sales to the domestic sector in 2003, and there are just fifteen public electricity suppliers in the UK (DTI 2004a). However, there are considerably more suppliers of coal and heating oil. Introduction of such an allowance scheme therefore would affect relatively few businesses, and most of those involved would be large businesses with the capability to adapt.

5.7.2 Easing the introduction of rationing

The nature of carbon rationing is such that it could not be introduced on either a regional or a voluntary basis to test its efficacy. It would need to be introduced nationally and in a mandatory way. However, there would be ways of simplifying the introduction of carbon rationing to reduce initial complexity and confusion. For example, initially public transport journeys could be excluded from carbon rationing as these account for only a small amount of personal motorised travel. In addition, carbon rationing could be introduced with no annual reductions initially to give people time to understand and start adjusting to the new system.

Starting carbon rationing in the UK prior to the next post-Kyoto international agreement would help get the framework in place before really serious reductions need to be made. A possible timetable would be:

2005-2007: making the public case for carbon rationing, and consulting about how it could be introduced

2008: begin introduction of rationing and supporting administrative systems

2009: trial year, where carbon ration cards can be used voluntarily by people to give them experience of where their carbon emissions arise
2010: second trial year, where people are given equal carbon rations, compulsory use of carbon allowance cards, and full annual statement of where their emissions arose and how much over or under their ration they were – but no financial penalties at the end of this year
2011 – onwards: rationing fully introduced, with falling annual allowances and strict use of carbon allowance cards for all transactions involving carbon-based energy use.

This timetable is far slower than for the introduction of food rationing in the second world war, which happened within weeks of the declaration of war. In terms of administration, rationing could be introduced much more quickly than in the timetable above. The limiting time factor would be getting political and public support for carbon rationing.

5.7.3 Making awareness of carbon emissions part of everyday life

There is currently little information available to consumers, householders and travellers about the carbon impacts of their decisions. One exception is that carbon emission figures (in terms of grams of carbon dioxide per kilometre — gCO_2/km) are published in advertising material for new cars. In addition, there are plans at an EU level to include carbon emission figures on energy bills (Boardman & Palmer 2003). However, with carbon rationing, carbon becomes a parallel currency and the level of information and education on carbon issues will have to increase considerably.

The scale of education and information provided on food rationing in the second world war shows the effort required. There was a comprehensive information campaign using radio, magazines, leaflets, posters and so on giving recipes for the new types of food (such as powdered egg), suggesting how to economise with food while still providing healthy meals and persuading people to grow their own vegetables (Zweiniger-Bargielowska 2000). Enabling people to live well on food rations was a key government aim and taking pride in doing so became part of the national culture. This is the scale of the transformation which would also be needed in information about and attitudes to carbon rations.

The following suggestions are some of the ways in which the carbon impacts of decisions could be made more transparent:

- smart bills: including carbon emissions on gas, electricity, fuel oil and other fuel bills;
- smart meters: gas and electricity meters to be upgraded over time to include a running total of carbon emissions, and provide comparisons with previous periods;
- smart receipts: including carbon emissions on petrol and diesel receipts;
- enhanced petrol pumps: displaying carbon emissions as well as price and quantity ;

- 'carbon-ometers': adding a carbon counter to standard car, motorcycle and moped displays, allowing the driver to have a record of total carbon emissions, plus a trip carbon calculator (as is equivalently available on the mileometer);
- carbon responsibility in advertising: all flight tickets and travel promotional material (such as adverts in the media, outdoors and on the web) to include equivalent carbon emissions;
- carbon labels: energy labels on appliances and light bulbs to include average annual carbon emissions;
- carbon promises: insulation materials (such as loft insulation) and home improvements such as double or triple glazing to be promoted in terms of the carbon as well as energy savings they can provide;
- carbon-rated homes: all houses, new and second-hand, to be sold with an energy survey and an estimate of average annual carbon emissions in use, plus tailored advice on how to reduce the emissions. Tenants would also need carbon information from their landlords.

Some of these ideas could be introduced by extending existing information provision methods, as examples in Table 5.4 indicate.

Table 5.4: Opportunities for adapting existing energy policies under a carbon rationing framework

Policy	Existing characteristics	Changing to a carbon emissions basis
EU energy labels, Energy Saving Trust 'energy efficiency recommended' labels	Based on the relative efficiency of appliances	Would need to change current basis first from relative efficiency to total consumption. For EU labels there would be issues around different EU electricity carbon intensity, and between UK energy companies to be resolved.
Building regulations for new homes	Based on meeting thermal performance standards, or a Carbon Index (carbon emissions for space and water heating per square metre). (ODPM 2001)	Base standards on household carbon emissions, independent of fuel used. This has already been considered as a possibility (ODPM 2004). However the proposed standard for 2005, although based on a carbon target per square metre, allows electrically and oil heated houses more emissions than properties heated with gas.
Energy Saving Trust 'energy efficiency' campaign	Focus is on individual actions and technologies which can save money and energy.	Would have to include carbon emissions and overall limits as well as energy and money savings. Much of the detailed advice about how to make savings would remain the same.

Industry agreements on efficiency	For example, for TVs and VCRs industry average standards and improvements agreed (Fawcett, Lane, & Boardman 2000).	People would need individual labels to tell them how much carbon the piece of equipment they were purchasing would emit.
Energy bills	No present requirement to provide any information about carbon emissions. However there are EU plans to include environmental information on energy bills (EU 2003) and research has been carried out on how best to do this (Boardman & Palmer 2003).	Annual carbon emissions statements could be included as part of the bills.

There are many energy efficiency policies which can be re-oriented towards carbon saving as their primary goal. This can begin immediately, without the need for carbon rations to be introduced. However, as Chapter 2 made clear, current policy is not achieving energy savings, so simply re-orienting it towards carbon savings would not be sufficient. These policies would offer information, incentives and advice, but will help achieve real savings only within a carbon cap.

New businesses and public sector organisations would also be expected to emerge to meet people's need to manage their carbon emissions, and existing organisations would take on new roles. One possible new organisation would be 'CarbonWatchers' - a community information and support scheme equivalent to diet schemes such as WeightWatchers (Hillman & Fawcett 2004). Based on the diet clubs template, it would provide its members with booklets / electronic information explaining the carbon impacts of different purchases and travel options, set reduction targets for individuals, hold regular audits (the equivalent of weigh-ins) and provide both professional and peer support for participants. Monitoring personal emissions would provide a practical means of appreciating the role of different energy-dependent activities in the total budget and of developing coping strategies to avoid excess consumption.

Energy companies could expand their existing role, by offering their customers carbon management services. They could develop 'smart meters' which informed people how much of their carbon ration for that year was left, which appliances were using most energy, how much carbon could be saved, for example, by reducing time spent in the shower, or by only heating bedrooms in the late evening. Alternatively, the companies could install sophisticated carbon management systems in houses which took these decisions automatically.

These are just some of the initiatives which would improve householders' understanding of their carbon emissions. New businesses and organisations to help people to manage and reduce emissions would no doubt be set up. In fact there are already several such businesses, for example both Future Forests and Climate Care sell carbon offsets (although there is controversy around the efficacy of carbon offsets (Muir 2004)). Advice on energy saving and carbon emissions is already available from a range of organisations, e.g. Global Action Plan, Energy Saving Trust. With proper information and advice, people should find it possible to be able to use this new 'currency' quickly, particularly as it will become an increasingly important part of life.

5.7.4 Discussion

Having presented the idea of carbon rationing to several audiences, one of the most frequent questions is 'how do we get from here to there?' In other words, how can the perceived gulf between the present world and the radical changes that would be required under carbon rationing be bridged? Is it credible to claim that carbon rationing could be a 'practical policy'? This section has indicated a timetable for the introduction of carbon rationing, the many supporting information and advice services which could be developed, and some suggestions about how existing policies could be transformed to support carbon rationing. These ideas are intended to show that rations could indeed be implemented in the real world, in a way which people would find acceptable. However, it would be unrealistic to suggest that introducing carbon rationing would be socially and politically easy. Although it can be considered as simply a method to achieve an already agreed target of 60% reductions, it would be a big change from current policy.

5.8 Wider implications of carbon rationing

In this section some of the wider implications of carbon rationing are considered briefly. This includes the extension of carbon rationing to the rest of the economy, followed by the sorts of social and lifestyle changes which might be introduced with carbon rationing. Finally there is speculation about the likely relationship between future energy prices and carbon rationing.

5.8.1 Carbon rationing for the rest of the economy

In order to make 60% savings throughout the economy it will be necessary to have a system in place to manage downwards the emissions in the half of the economy that is not subject to personal carbon allowances. As mentioned earlier, Anderson and Starkey are working on the form this could take within their DTQ framework (Anderson & Starkey 2004). It can be argued, that if the cap is set correctly, EU ETS provides a mechanism for most of the non-domestic sector. For the non-domestic sector, the considerations of what constitutes equity are likely to be rather different than for the domestic sector, and this may be crucial in designing a system. When the equivalent of carbon rationing is introduced for these sectors it will result in a reduction in the carbon intensity of goods and services, and it would be expected that higher carbon goods and services would become more expensive relative to the lower carbon alternatives. Householders' indirect carbon emissions will fall.

5.8.2 Social and lifestyle changes

Carbon rationing will inevitably introduce changes in lifestyle — both welcome and unwelcome. Some indirect social benefits of carbon rationing were identified in Hillman & Fawcett (2004), including health benefits from more journeys being made on foot and by bicycle and a reduction in fuel poverty as the thermal condition of housing is improved to enable people to live within the ration. Although people will be able to choose how to live within their ration, and which aspects of their lives to change, given the lack of technological fixes for motorised transport, particularly air transport, travel options are likely to narrow. Presently, travel to distant locations is not only seen as a benefit in its own right, it is also symbolic of social and economic success. However, under carbon rationing, there will be much less scope for this, particularly flying to foreign countries or within the UK. There can be little doubt that many will view the prospects of this as a considerable limitation on their choice and a distinct reduction in their quality of life.

5.8.3 Supply side issues and prices

Economic and supply side issues are beyond the expertise of the author to address in any detail. It is clear that the introduction of carbon rationing in the UK, within a world-wide C&C framework, would have a profound effect on the fossil fuel business. What would happen to the price of fossil fuels in the UK (or worldwide) under conditions of carbon rationing but no shortage of supply? (As explained earlier, there is many times more carbon contained in oil, gas and coal stocks than can be safely released to the atmosphere.) This would depend partly on the behaviour of the energy extractive industry, but it seems reasonably likely that energy prices might go down as demand for fossil fuel energy fell. During the second world war, under food rationing, the government controlled the price of rationed foods as well as individual access to them. However, that was under conditions of restricted supply, which will not be the case for fossil fuels, so it not clear that the government would wish or need (or be able) to take any action on energy prices.

The relative price of different fuels could be expected to change. Lower carbon fuels, such as renewably generated electricity, would be in greater demand, so prices might rise. The higher carbon fuels, such as oil and coal, might fall in price to encourage use despite their carbon penalties.

5.9 Summary and conclusions

The UK, in common with most other countries, needs new ways of making carbon savings. As explained in Chapter 2, although this country is likely to meet its Kyoto target it is extremely unlikely to meet its 20% carbon dioxide reduction target by 2010. This chapter proposes personal carbon rationing as the UK framework within the larger international solution of contraction and convergence. Calculations have been undertaken which demonstrate that a personal carbon rationing scheme would cover just over half of the UK's carbon equivalent emissions (including those from international air travel).

A system of national personal carbon rationing, based on the same principles as the international solution of contraction and convergence, should be effective in limiting damage from climate change. The principle is the same as that used at an international level: reducing greenhouse gas emissions is a benefit needed by all the earth's people and equal rights to emit carbon are as applicable at national as at international level. Following a description of the features of a UK personal carbon rationing scheme, there is a more detailed debate about different interpretations of equity, the virtues of a mandatory versus voluntary system and some calculations showing what the personal ration would be under different scenarios, and how this might affect individuals.

Administratively, putting carbon rationing in place should be much less challenging than the experience of introducing food rationing at the start of the second world war. It would require information on the carbon consequences of purchasing, usage and travel decisions to be readily available. Energy bills would become key providers of information, not only on costs but also on how much carbon allowance the householder had used up. There would be many new ways of informing people of their carbon emissions, and new business opportunities would arise to help people to reduce their emissions. Existing energy efficiency policies and information systems could be adjusted to meet the new carbon reduction goal. A key advantage of carbon rationing is that it provides an overall framework for carbon savings, within which a variety of individual responses can be adopted.

Past experience has shown both that UK-wide rationing systems can be implemented and be run successfully (food rationing in the second world war) and that international solutions to global environmental problems can be found (the hole in the ozone layer). Neither of these examples is a close analogy to the problems of carbon rationing and climate change, but both offer some practical lessons as well as providing good examples of regulated restrictions leading to positive outcomes.

In Chapter 6, carbon rationing will be considered more critically, its effects on different groups and individuals will be discussed, and it will be compared with an alternative policy approach, carbon taxation.

Chapter 6 - Analysis of personal carbon rations

6.1 Chapter overview

Chapter 5 presented a scheme for carbon rations in considerable detail. This chapter takes a more critical look at carbon rationing, the principles on which it is based and the practical outcomes of the scheme.

First of all the practical implications of carbon rationing are explored. How would equal rations impact on different individuals and groups in society? This question is first explored in general terms. Then, in order to understand in more detail the likely effects of carbon rationing on individuals, original case study data on carbon emissions have been collected and analysed. The data illustrate the wide range of personal carbon emissions in the UK at present: a variation of a factor of 12 for a sample of 32 individuals was found. The data also show how variable individuals' carbon emissions patterns can be, with very different proportions of emissions coming from domestic energy, land transport and air transport.

Following this, detailed data analysis considers the current differences in carbon emissions between different income groups and people in different household sizes and properties of different ages. Overall, carbon rations would be progressive because people with lower incomes are responsible for lower emissions than those on higher incomes. Proxy data have to be used to carry out this analysis, and the complications and limitations this creates are discussed.

Potential problems with carbon rationing are identified and explored in some detail. The problems chiefly relate to operational difficulties and the consequences of rationing for particular groups, rather than challenging the principles of carbon rationing. Potential solutions and counter-arguments have been presented. Finally, carbon taxation is discussed and compared with carbon rationing as a method for making carbon savings. Despite having some advantages, the argument is made that carbon taxes do not offer the same advantages of equity and certainty of savings as would carbon rations.

6.2 Methodology

A lack of data on personal carbon emissions has been identified – the only data that are available are based on average values for groups of individuals. In order to address this gap in knowledge, a data collection exercise was undertaken using questionnaires. Although the sample which resulted is small and not necessarily representative of the UK, it does allow discussion of the range of individual carbon emissions and of variation in patterns of personal energy use for the first time. The methodology is discussed and described in detail in section 6.4.

This chapter also brings together existing secondary information in new combinations to derive insights into variations in carbon emissions. For example, to investigate how personal carbon emissions vary between income groups, existing data from the Family Expenditure Survey has been combined with fuel price and fuel intensity data, to give an estimate of carbon emissions per household income decile. The methodology used has been compared with those of other authors who have addressed similar questions. In addition, the model developed in Chapter 4 has been used to look at carbon emissions by property age over time.

In order to look critically at carbon rationing, it is necessary to identify weaknesses and criticisms of the idea. However, there is a lack of academic or published critiques of carbon rationing. So, the limited literature has been supplemented by feedback received by the author at events when carbon rationing has been presented to various audiences. Literature review has also been used to investigate carbon taxation.

6.3 Would rationing be equitable in practice?

Equity is one of the key claimed benefits of carbon rations, along with certainty of savings. However, this does not mean rationing would have the same impact on everybody. The case for carbon rationing is that giving each person equal rights to emit carbon seems the most equitable possible scheme. The case against is stated clearly in a Ministry of Food second world war memorandum, quoted in Zweiniger-Bargielowska (2000):

"Rationing is essentially inequitable; it provides the same quantity of an article for each person without any consideration of their needs or habits or of their capacity to secure alternatives".

Variation in needs, habits and capacity to secure alternatives are very evident in energy use, and these are discussed below.

6.3.1 'Needs and habits'

Neither equal carbon emissions nor equal energy consumption allowances equate to equal energy services. To take a specific example of this general statement, Figure 6.1 shows how an average carbon allowance for space heating would translate into different internal temperatures depending on the carbon intensity of the fuel used and the efficiency of the heating system. The figure of 400kgC for a household carbon allowance for space heating is based on the average carbon emissions generated per pre-96 household for that purpose in 1996 (from TF model).

This equates to 18,000kWh of gas or 6,600kWh of electricity. The internal temperature this energy consumption would achieve in an average pre-1996 dwelling in 1996 is shown for different efficiencies of the gas heating system and for electric heating (which is 100% efficient by definition). The temperatures were calculated using the TF model described in Chapter 4. Electric heating would result in a temperature of 13.7°C, a 50% efficient gas system 15.6°C and a 90% efficient system would achieve 20.2°C. Thus an average carbon ration could lead to an internal temperature of anywhere between 13.7°C and 20.2°C in a pre-96 dwelling of average size, built form and building fabric.

Figure 6.1 does not show the full range of energy services that could be achieved from equal heating allowances. The true temperature range achievable from a 400kgC carbon ration would be far greater than six and a half degrees, given the wide variation that actually exists in dwelling size, built form, efficiency of building fabric, and the possibility of using renewable fuels. More efficient homes could achieve higher temperatures, and emit less carbon. For example, a semi-detached house of 80m^2 built to the proposed 2005 building regulation standards, will only generate 163kgC emissions (40% of 400kgC) to achieve a temperature of 21°C (ODPM 2004). In addition, depending on the occupation level of the property a higher or lower carbon ration would be available for heating – 400kgC is based on average household size. Finally, as explained in Chapter 4, internal temperature is not a complete measure of energy services, because it can represent different levels of thermal comfort depending on levels of clothing, activity and other environmental variables.

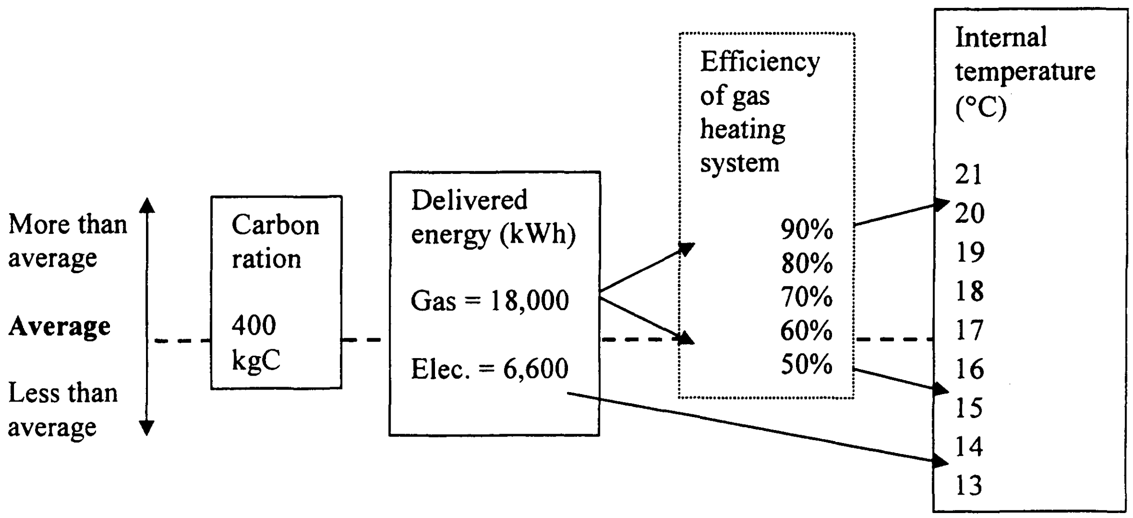

Figure 6.1: Internal temperature achievable on an average carbon ration for gas and electricity use in the average pre-96 dwelling, 1996

For cars, which are used for most personal travel within the UK, only two key factors intervene between carbon emissions and energy services: the choice of fuel and the efficiency of the car. Carbon emissions from diesel cars are typically 20% lower per km than those from petrol cars (Vehicle Certification Agency 2004). At present, carbon emissions for new cars (excluding 2 seaters) range from 104gC/km (Toyota Prius – a hybrid electric car) up to 332gC/km for a diesel 'sports utility vehicle' or 570gC/km for a petrol sports car. However, for more conventional cars the upper limit is generally around 190gC/km (diesel) to 210gC/km (petrol) (Vehicle Certification Agency 2004). Thus possible vehicle emissions per km for the majority of new cars vary by a factor of two. The relationship between carbon emissions and energy services is much less complex and variable than for energy use in households.

In general, for household energy, efficient end-use equipment, well insulated homes, lower carbon energy sources and renewable energy all create a disconnection between carbon emissions and energy services (Figure 6.2). It is this disconnection that offers people positive opportunities to reduce their carbon emissions without sacrificing energy services which are important to them. In addition, the size of a person's home will affect the energy services available to them, for example, a smaller home will allow warmer rooms than a larger one, given the same carbon allowance. Together these factors mean that equitably distributed carbon allowances could result in very inequitable levels of household energy services.

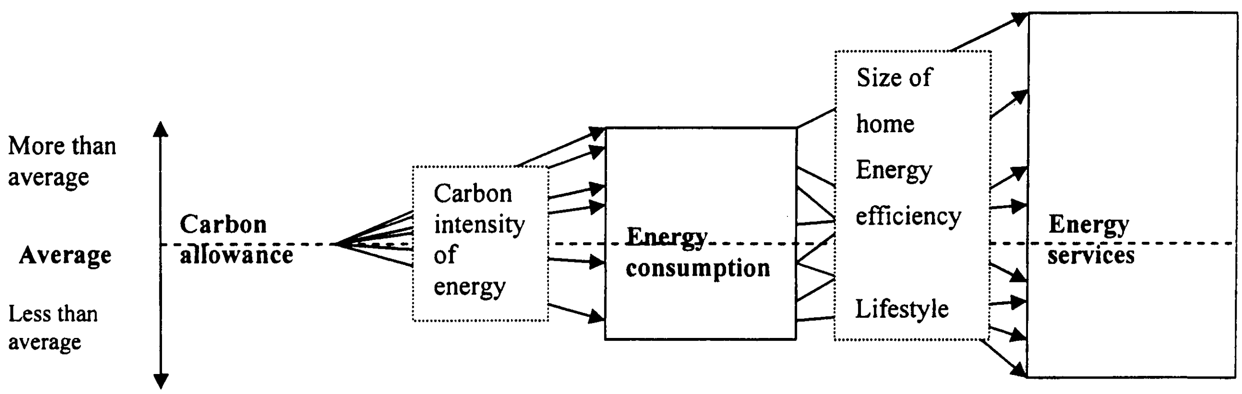

Figure 6.2: An average carbon allowance can lead to very different levels of energy consumption and energy services

This raises the question of whether it would be possible or desirable to base an emissions scheme on giving people access to equal energy services, rather than equal carbon rations.

There is no simple index of energy services – it consists of a wide range of services including clean clothes, warm rooms, mowed lawns, hours of TV watched and refrigerated food. People do not have equal wishes or needs for these services and the idea of 'equality of energy services' may not be a useful one.

Similarly, an allocation scheme based on what energy or energy services people 'need' (as opposed to want) would be extremely difficult, if not impossible, to devise. Dobson (1995) reflects that building a theory of need is notoriously difficult. Owens & Cowell (2002) report that there is an immense literature on the subject of needs versus wants. They found that some authors retained an aversion to distinguishing between wants and needs, while others have perceived a morally significant difference between 'goods of the needs category' and 'goods of the wants category'. Wilhite and Lutzenhiser (1997) suggest that determining the minimum amount of resources needed for any consumption activity is fraught with both analytical and political pitfalls. They take refrigeration as an example and state that *"no one really 'needs' a refrigerator, but given the packaging and distribution of foods, it is difficult to participate in normal food provisioning and eating without one"*. The authors then debate what size of refrigerator and freezer might currently be considered the minimum reasonable in terms of food storage, and note the many social reasons, including working and shopping patterns, householders' wishes to be seen as good providers and the influence of kitchen designers which serve to increase the minimum size 'needed'. They note that what is now taken to be conventional and basic social hardware was once regarded as unnecessary, luxurious or even frivolous. The authors conclude that there is constant renegotiation of what are regarded as basic needs, usually in the direction of increasing consumption of energy and other resources.

There is then no clear agreement that energy needs could be distinguished from energy wants. Even if needs could be agreed at a particular point in time, e.g. a requirement for everyone to have a ration sufficient to allow them to achieve an internal temperature of 18°C in their home, actually designing a system to deliver such differentiated allowances would be impossible, given the wide variety of personal circumstances, occupation levels and variation in the housing and energy-using equipment stock.

6.3.2 'Capacity to secure alternatives'

People will not have the same capability of achieving 'off-ration' or lower carbon energy supplies. For household energy, currently the main household level options for renewable energy are solar water heating (SWH) and photo-voltaics (PV). As noted in Chapter 4, only an estimated half of all properties are suitable for SWH, due primarily to their orientation, and this would also apply to PV. Of conventional fossil fuels, the lowest carbon option is natural gas which is available to around 80% of UK households leaving the remainder with higher carbon heating fuels to choose between.

A key constraint on the capacity of households and individuals to secure alternatives is money. Many lower carbon options, e.g. solar water heating, and carbon saving technologies, such as a new, efficient boiler, require capital investment. However, this is not universally true, generally more energy efficient cars are cheaper than less efficient ones, which tend to be larger and more upmarket. In addition, as Chapter 4 identified, changes in behaviour can offer significant energy savings without requiring financial investment. In the current government schemes there is additional help for lower income households in making their homes more energy efficient (see Chapter 2). Nevertheless, for technology solutions which do require additional investment, lower income householders will be at a disadvantage. Householders who are tenants rather than owner occupiers may also face additional difficulties if their landlords are unwilling to invest in improvements on their behalf.

6.3.3 Discussion

This discussion in principle has shown that equal carbon rations would lead to unequal access to energy services, particularly for household energy use, due to the current wide range of property and equipment efficiencies and variation in living arrangements and lifestyles. Similarly, the unequal capacity to adjust that people have, either in technical, financial or social terms, means that adapting to carbon rationing will fall more heavily on some people than on others. Whether this is of concern in public policy terms probably depends on the numbers of 'winners' and 'losers', and particularly on whether it is disadvantaged groups who have less capacity to adjust, or are less able to buy additional rations, who suffer most. The following sections use a variety of empirical, modelling and secondary data to further consider how carbon rationing would affect different individuals and groups in society.

Unequal effects could be compensated to some extent by government policy. Those without sufficient income could be helped either to reduce their need for carbon (ideally) or given more rations from the pool of those sold back to the government. It would also be possible to build special allowances into a carbon rationing scheme (as discussed in Chapter 5). For the better off in society, since there is to be trading, people who don't have sufficient carbon rations to meet their desired lifestyle can buy more. Although the unequal consequences of carbon rationing could be of political concern, unequal consequences do not prove that the 'equal shares' basis is flawed. There is little likelihood of being able to devise an alternative scheme based on individual 'needs' for energy service / carbon emissions. Even if such a scheme could be devised, it would effectively subsidise those with higher carbon lifestyles at the expense of the more carbon thrifty.

6.4 Case studies of personal carbon emissions

6.4.1 Introduction

There is currently no published data on personal carbon emissions on an individual basis[1]. To rectify this gap, empirical data have been gathered from a number of individuals and their emissions for 2003 have been calculated. This case study data were collected in order to undertake analysis on the variation in personal carbon emissions, and to identify how different components of energy use contribute to this variation. The aim was not to try to explain the variation in terms of underlying factors, such as individual income, household size, access to different transport options etc. Instead, secondary data were subsequently used to look at some of these factors (section 6.6).

6.4.2 Questionnaire design

The questionnaire used to collect the case study data was a simplified carbon audit, based closely on that developed with Mayer Hillman (Hillman & Fawcett 2004). In order to make the carbon audit relatively easy to complete, the questions were kept to a minimum. A copy of the questionnaire is reproduced in Appendix 7. Respondents are asked to use energy bills to provide information on gas, electricity and other household fuel usage in 2003. For travel, respondents are asked to estimate the distance travelled by each motorised mode, or to give a description of the routes travelled. Socio-economic questions, other than about occupation, were not included, because the planned sample size would not be big enough to undertake analysis based on socio-economic differences between respondents.

The questionnaire was piloted on a small number of individuals, who completed it without help from the author. Since none of the respondents reported difficulties and all completed the questionnaire satisfactorily, the initial questionnaire design was unchanged. In a small number of cases, the respondents were helped through the process and their energy bills were read, but the majority of respondents completed the form themselves.

6.4.3 Sampling strategy

From the start, the decision was made not to try and achieve a sample which would be large enough to be representative of the UK population, because this would be beyond the resources of the author. In the National Travel Survey, samples of 3,000+ individuals are aggregated over three years, to give a suitably large sample size of over 9,000 (DfT 2004a). The English House Condition Survey used a sample size of 24,700 for household interviews in 2001 (ODPM 2003).

[1] Carbon emissions of a small number of households have been calculated by Marshall, who has developed his own methodology for calculation of carbon emissions (Marshall 2002). However, this work has not yet been published (Marshall 2004).

The size of a representative sample for carbon audits would depend on the type of analysis to be carried out. The required sample size has not been calculated, but it would clearly exceed the tens of audits the author planned by at least one or two orders of magnitude.

Initially, it was planned to try to gain some responses through distributing questionnaires at a series of public talks the author was involved in during June and July 2004. At a talk given by the author and Mayer Hillman to present their book in Oxford during June 2004, about fifteen carbon audit questionnaires were handed out to people who requested them. Although all of the potential respondents had volunteered to complete carbon audit forms, none of these was returned. Similarly the author had a fairly poor response from fellow participants on an 'Eco building and design course' at the Centre for Alternative Technology. Only four out of sixteen responded with completed forms, despite all sixteen having volunteered and reminders being sent. There may be an element of people 'not wanting to know' what their impact is on the environment (a phenomenon also identified by Marshall and Lynas (2003) and discussed in Hillman and Fawcett (2004)). For many people, even those who aspire to 'green' lifestyles, the carbon audit would show that their impact on the global atmosphere is considerable, and possibly much greater than the UK average. However, without being able to question the non-respondents (whose details were not generally recorded), it is not possible to determine why there was such a poor response rate.

Given these poor response rates, it was decided a different approach to persuading respondents to complete the audit was required. A strategy was adopted of approaching relatives, friends and colleagues of the author and, via them, their contacts. This could clearly lead to a less varied sample than other approaches but, given the limitations of time and the fact that the sample would in any case be unrepresentative, it was decided this method of recruiting respondents was acceptable. In order to encourage a response, the author offered to send respondents an analysis of their carbon emissions, a comparison with the UK average and some advice on how carbon emissions might be reduced. An example of this feedback is included in Appendix 8. In total a sample of 35 people was achieved, with 32 returning usable questionnaires. Potential respondents were approached from a variety of household sizes and with different heating fuels – two factors which are known to influence household carbon emissions. The characteristics of the sample compared with the UK population are described in section 6.4.5.

6.4.4 Calculations

The carbon intensity factors listed in Table 2.2 were used to convert gas, electricity, oil and solid fuel energy consumption into carbon emissions. The factors in Table 6.1 were used to convert journey distances in km to carbon emissions in kgC. The factors for calculating carbon emissions from travel were devised by Mayer Hillman (Hillman & Fawcett 2004).

Emissions for car travel are given for the driver only. However, the average car journey in Great Britain contained 1.59 people in 2002/03 (DfT 2004b). By allocating all vehicle emissions to the driver, those who travel greater distances as a driver than as a passenger will appear to have greater than their 'true' emissions, and those who travel by car predominantly or solely as a passenger will have artificially low emissions. Despite the inaccuracies of the method chosen, it was judged necessary because of the difficulties of asking drivers to estimate the average occupancy of their cars during 2003 and of asking passengers to estimate the distance travelled by car and how many other people were in the car.. A more detailed method of collecting travel data, such as travel diaries, would be required to get accurate enough information about travel patterns to warrant calculating car emissions per person, whether passenger or driver. Allocating all car emissions to drivers increases the apparent variation in personal travel emissions – as those of non-drivers are lower than they should be, and those of drivers are generally higher.

Respondents were not asked to state what model of car they drive, and subsequent calculations are based on the carbon emissions per kilometre for an average petrol car or an average diesel car. There is not sufficient data to use actual emissions figures for individual cars: carbon emissions figures are only available for new car models, under test conditions (Vehicle Certification Agency 2004). For passenger travel by public transport, average figures are used, covering the relatively energy-inefficient times of the many off-peak hours when there are few passengers as well as the peak hours when travel by public transport is more heavily used.[2]

Table 6.1: Factors for translating travel distances into carbon emissions

Travel mode	**Carbon emissions in kgC per km / (kgCe/km for air travel)**
Petrol car (as driver)	0.055
Diesel car (as driver)	0.038
Rail: intercity	0.030
Rail: other services	0.044
Rail: underground	0.019
Bus: London	0.025
Bus: outside London	0.046
Express coach	0.022
Air: within Europe	0.139
Air: outside Europe	0.087

Source: Hillman & Fawcett 2004

Travel by sea and by motorbike have not been included, because they are relatively minor travel modes. In addition, figures for travel by sea are not readily available.

[2] The figures in Table 6.1 demonstrate that many forms of public transport differ little from travel by car in terms of emissions per person per kilometre.

For long distance road or rail travel, and for travel by air, respondents did not generally estimate the distances travelled and instead gave details of their starting and destination points. To translate this information into distances, the following web sites were used:

- For road or rail journeys within Europe and air journeys within the UK: www.viamichelin.com
- For air journeys beyond the UK: www.indo.com/cgi-bin/dist, except for some European destinations which are not in the database, in which case www.viamichelin.com was used.

The www.indo.com website uses data from the US Census and a supplementary list of cities around the world to find the latitude and longitude of two places, and then calculates the distance between them (as the crow flies). This will not give an exact distance travelled by air, in part because planes normally travel along great circle routes, which are the shortest routes between two points on the surface of the earth and lie on a plane passing through the earth's centre, although national airspace restrictions and jet streams may also influence the route (Choose Climate 2004).

For those people who had chosen renewable electricity tariffs (five out of 32), their emissions from electricity were set to zero. There is a complex debate about the value of signing up to a renewable energy tariff and the extent to which this results in 'additional' renewable energy (FOE 2004). However, well designed renewable energy tariffs should provide additional renewable energy beyond that which is already legally required, and on this basis it is assumed that renewable electricity customers have zero carbon emissions.

6.4.5 Results

Individual carbon emissions have been summarised into domestic energy use, land travel (travel by car, bus and train) and air travel, and are presented in Figure 6.3. The columns with stars above them are those where the individual has chosen a renewable electricity tariff. Full details of the original data and carbon emissions are presented in tables in Appendix 9.

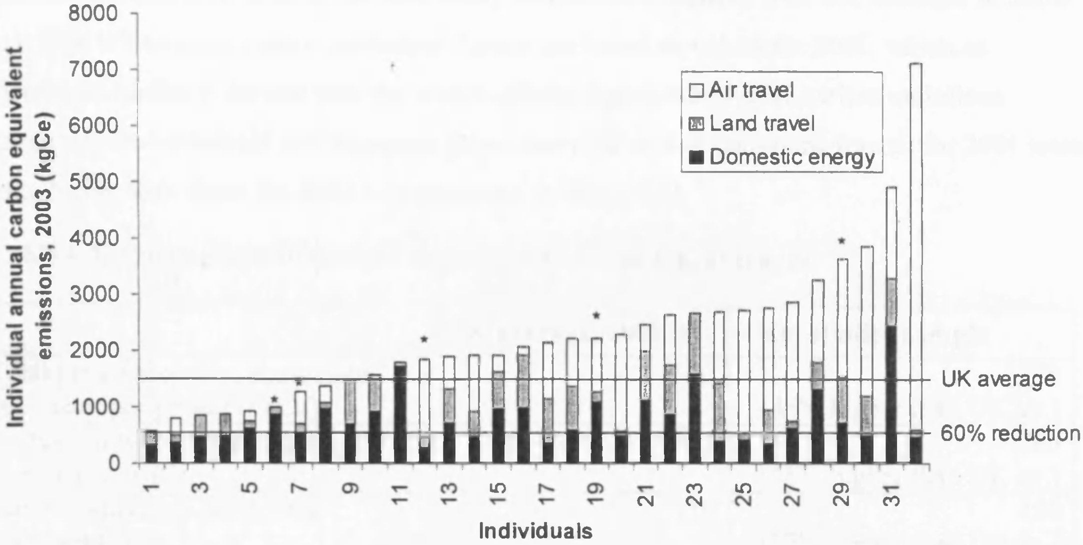

Figure 6.3: Individual annual carbon equivalent emissions by source, UK, 2003

The data show a huge range of personal carbon emissions with the highest emitter being responsible for twelve times the emissions of the lowest (Table 6.2). They also show the huge variation in the way an individual's carbon emissions are made up. For Respondent 32, 92% of carbon emissions came from leisure air travel, by contrast Respondent 11 did not travel by air and 95% of their emissions were from household energy use. Of the sample of 32, eight did not travel by air in 2003, and their total emissions were on average just over half those of the group which did fly. The data demonstrate 23 respondents (72% of the total) were responsible for above average UK carbon emissions for 2003.

Table 6.2 demonstrates the ratios between the highest and lowest carbon emissions by type of energy use, with air travel varying the most between individuals – by a factor of 46 between those who did travel by air. The lowest variation between individuals was for household energy use – although a factor of nine still seems surprisingly high.

Table 6.2: Comparison of lowest and highest values from case study individuals

	Ratios lowest: highest values
Total carbon equivalent emissions	1:12
Carbon emissions from household energy use per individual	1:9
Carbon emissions from household energy *per household*	*1:8*
Carbon emissions from land transport	1:19
Carbon equivalent emissions from air travel (for people who have undertaken air travel)	1:46

Some of the characteristics of the case study sample are compared with UK averages in Table 6.3. The UK average carbon emissions figures are based on values for 2001, which as mentioned earlier is the last year for which official figures which give carbon emissions separately for household and transport. (Note that total carbon emissions figures for 2001 were a little higher than those for 2002 – as presented in Table 5.1).

Table 6.3: Comparison of sample characteristics with UK averages

	UK average, 2001/02	Case studies sample
Total personal carbon equivalent emissions per person (kgCe)	1560	2270 (45% higher than UK av.)
Carbon emissions from household energy use (kgC)	700	780 (11% higher than UK av.)
Carbon emissions from land transport (kgC)	430	480 (12% higher than UK av.)
Carbon equivalent emissions from air travel (kgCe)	420	1010 (140% higher than UK av.)
Average household size *	2.3	2.1
One person households *	31%	31%
Households with children *	27%	16%
Households with one or two retired people (or over 60) *	30%	31%
Households using gas as main heating fuel	80% (author estimate)	84%
Households with renewable electricity tariff	Estimated at 50,000 in 2002, 0.2% of UK households	16% (5 individuals)

Sources: Household characteristics: Rickards et al. 2004, green electricity: FOE 2004

* Values for GB population

The comparisons show that carbon emissions from household and personal energy use for the case study samples were similar to the national average. However carbon equivalent emissions from international air travel were almost two and half times the national average. In total, average case study emissions are 45% higher than the UK average. Note that the UK average carbon equivalent emissions figure includes children (who must have lower than average adult carbon emissions as they cannot drive), whereas no children were included in the case studies.

In terms of household size, the case study sample average was lower than the GB average. This was largely due to the small number of households with children which were included in the survey. The author did try to get additional responses from households with children – but with little success. The proportion of one-person households and retired households was similar to the national average, as was the proportion of households with gas as the main heating fuel. Households choosing a renewable electricity tariff were considerably over-represented compared with the UK population.

Respondents were invited to contact the author with follow-up comments or questions after receiving their carbon audit. A number of comments were received, most of which either expressed surprise that their emissions were so high, or that the recipients had plans to reduce their emissions (usually by reducing flying / travel by car).

6.4.6 Reducing carbon emissions in the case study group

Of the case study sample, 23 out of 32 had higher than average carbon emissions. So what would the options be for these 23 individuals if they wanted to reduce their emissions to the national average? The highest priority is reducing air travel. Eighteen of the 23 had higher than average emissions from air travel, compared with 15 with higher than average land travel emissions, and 10 with greater than average domestic energy emissions. By reducing air travel alone, 14 out of 23 could reduce their emissions sufficiently to reach the national average. Many of these 14, while reducing their air travel from present levels, would still be able to travel considerable distances by air and stay below the average, e.g. case studies 12, 20, 25, 27 and 32. In addition, long distance rail or driving can be used as a lower carbon alternative for reaching European destinations. It is perhaps not surprising that reducing air travel is the most single important carbon reduction measure given that the case study sample as a whole has unusually high emissions from air travel.

Of the nine case study individuals who cannot reduce their emissions to the national average even if they cut out all air travel, all but one has higher than average emissions for both land travel and domestic energy use. On average their household energy emissions are 90% higher and their land travel emissions are 66% higher than the national average. This suggests they will have to address both patterns of household energy use and land travel. There are many options for doing both. Chapter 4 has already detailed the many technical and behavioural options that are available to reduce household energy use and carbon emissions. That chapter also showed that an approach which included both behavioural and technological changes could result in greater savings than either changes in behaviour or technology on their own. For transport, lower carbon options include reducing motorised distance travelled, switching from travelling by car to public transport, using a more efficient car and switching from petrol to diesel. Many different behavioural strategies are available for reducing distance travelled (Semlyen 2000), however, this does not necessarily mean it is easy to change existing travel patterns.

It would have been interesting to look in specific detail at how some of the case study individuals could reduce their emissions to the national average or below. However, to do this additional data would have had to be collected about the energy characteristics of their housing and detailed travel patterns.

6.4.7 Discussion

Data collection, calculations and accuracy

Two problems were encountered with completion of the questionnaire:

1. difficulty with reporting the units for gas consumption;
2. lack of availability of a complete year of household bills.

Gas meters can measure consumption in kWh, cubic metres and hundreds of cubic feet. Gas bill layout varies by company, and it is not always clear what the units are on the bill. In two cases the respondents had to be contacted again in order to clarify their gas usage figures and the units in which it was measured. Three respondents were unable to supply figures for a whole year of household energy consumption, and so their replies could not be used in the analysis. No other problems were found with completion of the questionnaire.

The data presented by respondents is likely to have been of varying accuracy. Good quality information should be available for household fuel use assuming people are able to read their energy bills correctly. However, estimates for transport energy use are likely to be less accurate, because people do not have good records of travel which is not undertaken by car (for which mileometers and subsequent MOT certificates can be used). The National Travel Survey (DTLR 2001a) bases its figures on seven day travel diaries kept by participants. For most people, it seems likely that travel by air is an unusual enough event to be recalled with accuracy. In addition to the problem of inaccurate reporting of travel, some emissions were not included in the totals: travel by motorbike - 1 respondent; travel by sea - 3 respondents; solid fuel as a supplementary heating fuel (where estimates of weight used were not available) - 2 respondents. By allocating all car emissions to drivers, the true variation in carbon emissions between different people is likely to have been overestimated. By contrast, by using average figures for car emissions, rather than basing this on the particular model people drove, the true variation in carbon emissions is reduced.

Consequences for carbon rations

This preliminary information on the range of personal carbon emissions presents a challenge to the practical implementation of carbon rationing. It shows that variations between individuals (even based on a small sample) can be very considerable. This has a number of consequences:

- Under carbon rationing, trading of rations will be very important and most people will want to buy or sell spare rations.
- It indicates there are likely to be large numbers of people, particularly those who fly long distances and want to continue to do so, who will have difficulty in reducing emissions to the national average. The challenge of reducing emissions by 60% by 2050 may be less onerous by comparison.

- The responses to carbon rationing are likely to vary hugely depending on how personal emissions are made up. In the examples highlighted earlier, Respondent 32 would need to cut down air travel considerably, whereas all of Respondent 11's actions should be directed towards improving the efficiency of their home, using lower carbon fuels and reducing domestic energy use via behavioural changes.

6.5 Other perspectives on individual carbon emissions

This section looks briefly at how carbon emissions can vary over time for the same individual, and how they might vary between individuals in the same household. The consequences of these types of variations are discussed.

Although carbon audit data above illustrate the current differences between individuals, they do not show how an individual's emissions might vary from year to year as his / her circumstances change. Annual variations are particularly likely for those who fly abroad, where a return flight to New York could add 970 kgCe to emissions, a figure greater than average annual individual emissions from household energy use. However it can also apply to household energy use, and emissions of an individual can vary considerably as their accommodation choice and household arrangements change. The data below (Table 6.4) shows how the author's household carbon emissions have varied over the past four years living in different properties.

Table 6.4: Author's changing annual household carbon emissions between different properties

Location	SAP	People per household	Gas (kWh)	Electricity (kWh)	Carbon emissions per household (kgC)	Carbon emissions per person (kgC)
Oxford 1	57	1	0	4,800	653	653
London	67	2	7,800	2,030	666	333
Oxford 2	72	2	14,400	1,700	951	476

Source: Author's records and calculations, using 2003 values for electricity carbon intensity.

By moving between properties and households, the author's carbon emissions from household energy have varied by almost a factor of two over a four year period. This variation was due largely to changes in the size of property occupied, the fuel used by the heating and hot water systems and whether or not the property was shared with another person - factors which cannot be easily altered once the decision to live in a particular place is taken. Although the efficiency of the properties was also relevant, in these cases it was not the crucial factor. A more general point illustrated by this data, is that change in household size with changing family stage or for other reasons can have a considerable influence on personal carbon emissions without a corresponding increase in energy services – this is discussed further in section 6.6.4.

By definition household energy use is shared equally by all the individuals in a household. However travel patterns are likely to differ between people in the same household. It is known that there are differences between the average travel patterns of people of different ages and genders. For example, men travel on average two fifths further on land than women in Great Britain. Length of travel also varies by age, with annual mileage increasing with age, reaching a maximum for both men and women between 40 and 49, declining thereafter (DTLR 2001a). Children's mobility patterns also vary very considerably from those of adults.

These glimpses into the further complexity of variations in personal carbon rations over time and between household members show that the many adjustments required if carbon rationing were introduced would go beyond simply use of energy. Considerations such as household size, locations of home and work and the fuel used in a household would become key factors in decision making. There are likely to be negotiations around who uses carbon rations for what purpose between people within a household. People may also want to 'save up' rations for special events – however, it would probably be necessary that rations had some sort of 'expiry date', because they would become more valuable over time as the individual ration reduced. Understanding variations in carbon emissions will be key to designing the details of a good carbon rationing scheme.

6.6 The effects of carbon rationing on different groups within society

6.6.1 Introduction

This section analyses the expected effects of carbon rationing on different groups in society. Ideally, carbon emissions data which included household energy and personal travel (including air travel) differentiated by social class, income, family stage and household size would be available. However, it is not and neither is there data on the combined amount of energy used by individuals or households for transport and household energy other than at a national level. Transport and household energy statistics are collected by different government departments, using separate questionnaires (this is discussed further in Chapter 7). To get an understanding of personal carbon emissions by different groups, proxy measures have to be used, and this inevitably introduces limitations into the analysis.

6.6.2 Recent research

Subsequent to the research for this thesis being completed, new analysis of greenhouse gas and carbon emissions have been published in October 2004 (Ekins & Dresner 2004, Francis 2004).

Both studies overlap with some of the research in this thesis. The studies are briefly described below, and their results are included in the following sections where relevant.

The study by Ekins and Dresner (2004), together with the associated background documents Dresner & Ekins (2004a) and Dresner & Ekins (2004b), was primarily concerned with researching the effects on low-income households of different environmental taxes. As part of the research, the effect of carbon taxes on household energy use was considered in some detail, as were various transport taxes. The effects of introducing DTQs (a policy proposal very similar to carbon rations, as explained in Chapter 5) were also investigated. This involved analysis of energy use by income group similar to that carried out by the author.

The Office for National Statistics have published a report called "The impact of UK households on the environment through direct and indirect generation of greenhouse gases" (Francis 2004). The report looks at greenhouse gas emissions in 2001 for households broken down by region, household size and age of the head of household (under 30, 30 to 64 and 65 and over). Francis states that no attempt was made to identify emissions by the level of household income due to limitations in time and data availability.

There are a number of methodological differences between Francis' research and that carried out in this thesis:

- Results are reported on a total greenhouse gas basis. It is not possible to separate out figures for carbon dioxide emissions from fossil fuel energy use (the subject of this thesis).
- The analysis is based on the National Accounts (NA) methodology of counting carbon dioxide and other greenhouse gases. This differs from the IPCC methodology which is used in this research. The NA methodology includes emissions from international aviation and international shipping and from fuels purchased abroad by UK residents. It excludes emissions from fuels purchased in the UK by non-UK residents.
- The aircraft emissions are not adjusted to take account of their true global warming effect (as described in Chapter 2).

Nevertheless, the Francis analysis is very interesting and key results are highlighted below.

6.6.3 Carbon emissions by income

The best available proxy data on a combination of domestic energy and transport fuel use by income is expenditure information. TheFamily Expenditure and Food Survey (ONS 2004) gives expenditure data for both domestic energy and personal private transport fuels by income decile, where decile 1 is the 10% of households with the lowest income and decile 10 is the richest 10%. Figure 6.4 shows how expenditure on domestic energy and motoring fuels vary per individual by household income decile. The data on which this figure is based are given in full in Appendix 10.

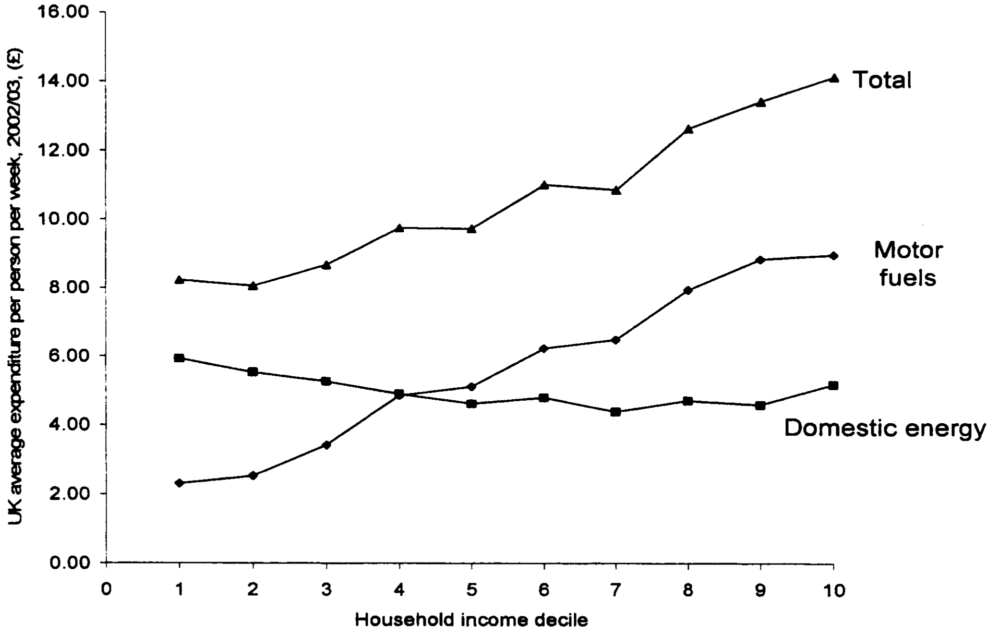

Figure 6.4: Expenditure per person per week on domestic energy and personal private transport fuels by household income deciles, 2002/03, UK

Source: ONS 2004

The data demonstrate that expenditure per person on domestic energy plus personal private transport fuels rises considerably with household income. Rising expenditure with income decile is driven by spending on motor fuels where the richest individuals spend almost four times as much as the poorest. Importantly, the number of people per household increases in parallel to household income; the average number rising from 1.3 to 3.2 between decile 1 and decile 10. Thus, although domestic energy expenditure *per household* rises with income (see Appendix 10), when domestic energy expenditure is compared on a *per person* basis it is the poorest individuals who spend most. In addition, people in the lowest decile spent 5.6% of their income on household fuel in 2002/03, compared with 1.9% spent by those in decile 10.

Because of the variation in household sizes, a simple comparison of household incomes is not necessarily a true picture of how income varies between the deciles. Adjustments can be made to produce 'equivalent' income figures per decile for two-person households. Such analysis increases the equivalent income of households in lower deciles, and reduces that of those in the higher deciles (Dresner & Ekins 2004a). However, this adjustment does not change the order of the deciles, and so for the purposes of this research, where no analysis is being carried out using absolute values of income, it is an unnecessary refinement.

Translating expenditure into carbon emissions

Expenditure on gas, electricity and motor fuels can be translated into carbon emissions by using information about the cost of each form of energy and the carbon emissions per kWh or litre of energy. Average prices for fuels, their carbon emissions per unit energy and consequently their emissions per pound spent (kgC/£) are shown in Table 6.5. The data show that each pound spent on motor fuels results in lower carbon emissions than a pound spent on household fuels. This largely result from the high levels of taxation on these fuels.

Table 6.5: Average price and carbon intensity of gas, electricity and motor fuels, UK, 2003

Energy source	Price per unit energy (£/unit)	Carbon emissions per unit energy (kgC/unit)	Carbon emissions per £ (kgC/£)
Gas	0.016 per kWh	0.05 per kWh	3.09
Electricity	0.066 per kWh	0.136 per kWh	2.06
Petrol	0.75 per litre	0.63 per litre	0.84
Diesel	0.77 per litre	0.73 per litre	0.95

Sources: DTI 2004a, DEFRA 2001a, AA 2004 – prices for June 2003

To undertake the next stage of the analysis these figures for kgC/£ are combined with expenditure per income group (Figure 6.5). These data show that carbon emissions from domestic energy are significantly greater than those from motor fuels for all income deciles (which contrasts with expenditure, where more is spent on motor fuels than on domestic energy for by people in higher deciles).

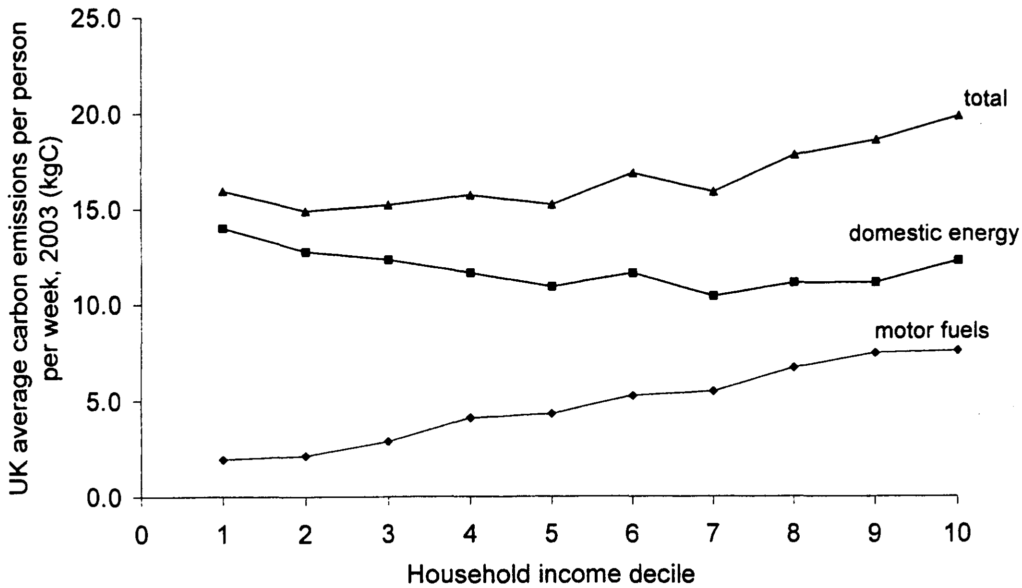

Figure 6.5: UK average weekly carbon emissions per person from travel by car and domestic gas and electricity use, by household income decile, 2002/03

Sources: ONS 2004, DTI 2004a, DEFRA 2001a, AA 2004

The total emissions per person by household income decile show that, for the five lowest income deciles, emissions per person are about equal, and that they rise gradually after that. The conclusion is that if everyone had equal carbon allowances and wished to continue with their pre-existing consumption patterns, there would have to be transfer of allowances from those in poorer households to those in richer households and a transfer of payments from richer to poorer to buy their spare allowance. It also demonstrates that an individual allowance scheme based on household energy only would be regressive, it would impact the poor more heavily.

However, this analysis is incomplete because it does not include carbon emissions from 'other' household fuels, energy use via public transport or travel by air, (because this data cannot be derived from expenditure figures). There is little variation in expenditure on public transport (i.e. rail, tube, bus and coach fairs) in income deciles one to eight, with higher expenditure in deciles nine and ten. In addition, public transport is a much less significant source of energy use than travel by car. Similarly, the average expenditure on 'other' household energy varies little between the income decile groups, and at an average of 7% of expenditure on household fuels they represent a minor component of expenditure. Therefore exclusion of public transport energy use and of other household fuels does not significantly affect the pattern of carbon emissions by income decile.

Also, a number of assumptions have been made by simply combining average prices with expenditure per income decile:

- It is assumed that average household energy prices apply equally across all income deciles. However there is evidence that poorer people tend to pay more per unit of energy than the better off. For example, in 2001 pre-payment electricity users (predominantly low income households) paid 12% more on average for the same amount of electricity than somebody paying by direct debit (higher income households) (Boardman & Fawcett 2002). An assumption of equal emissions per pound spent will tend to overestimate the carbon emissions of lower income people.
- If off-peak electricity is used in unequal ratios between different income groups, then this will distort the analysis somewhat. This is because off-peak electricity costs only around a third of standard electricity, but has very similar carbon emissions to all electricity. At present around one third of electricity is used off-peak (DTI 2004a).
- In the Family Expenditure Survey, motor fuel expenditure is not distinguished between petrol and diesel. DTI (2004a) figures show that 2003 retail sales were in the ratio 68% petrol to 32% diesel (by weight), but it is likely many small businesses buy diesel from retail outlets – so this ratio is unlikely to apply to household transport fuels. In the absence of good data, it is assumed all expenditure was on petrol.

The important omission is air travel, which is responsible for 27% of the average individual's personal carbon equivalent emissions, and which varies considerably by income. Air travel is predominantly undertaken by the richer members of society, with, for example, three quarters of all low cost flights being taken by the top three social classes (Bishop & Grayling 2003). There is no good proxy data on cost of air travel which can be used to estimate distance travelled. Expenditure on foreign package holidays increases considerably by decile, such that decile ten individuals spend seven times more than those in decile one (ONS 2004). However, this cannot be related directly to the proportion of expenditure on air travel or distance travelled.

In Figure 6.6, in order to get some idea of how air travel could affect total individual carbon emissions it has been assumed that air travel carbon equivalent emissions vary in the same way across the deciles as those from motor fuels. This probably underestimates the true emissions of those in higher income groups. However, given this assumption, the average individual in decile ten was responsible for almost 60% more carbon equivalent emissions in 2002/03 than somebody from deciles one, two and three. The inclusion of air emissions increases the gap in carbon emissions between higher and lower income individuals.

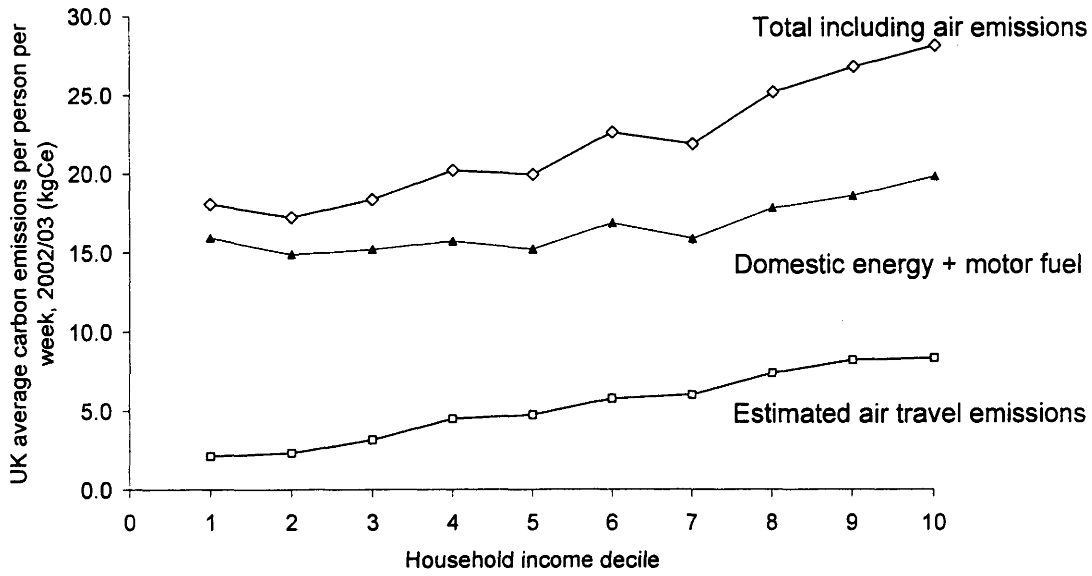

Figure 6.6: UK average weekly carbon emissions per person from private transport, gas and electricity use, and estimated air travel emissions by household income decile, 2002/03

Sources: ONS 2004, DTI 2004a, DEFRA 2001a, AA 2004

The simplifications in this analysis, which have been identified above, on balance probably mean that the emissions of higher income individuals have been underestimated. Nevertheless it is clear that, on average, individuals in lower income deciles have lower carbon emissions than those in higher deciles. Thus carbon rations would not unfairly disadvantage the poor.

Dresner and Ekins (2004b) carried out analysis very similar to that described above, the most significant difference being the way they estimated aircraft emissions. They identified the same problems with estimating air travel by income decile as the author. However, they decided to use data on expenditure on package holidays as proxy for the number of flights taken per year, the total number of flights from the International Passenger Survey (ONS 2003) and assumed that all holidays were to the same destination. As they recognised, this is a considerable simplification, which does not recognise the role of scheduled flights, the many causes for variation in expenditure on package holidays, and the variation in destinations which may be chosen by different income deciles. They do not report the consequent carbon emissions per income deciles, so the results from this method of estimation cannot be compared with that used by the author.

6.6.4 Carbon emissions and household size

There is strong evidence that carbon emissions from household energy use are likely to vary considerably by household size. As Table 6.6 illustrates, somebody in a one-person household, regardless of income, uses around twice as much electricity and gas and therefore produces twice the carbon emissions as somebody in a three-person household.

Table 6.6: Scale effects of household size on the use of domestic energy (one-person household = 100), England, 1996

Household size	Electricity per household	Gas per household	Electricity per person	Gas per person
1	100	100	100	100
2	137	129	69	65
3	165	142	55	47
4	180	156	45	39
5	192	175	38	35

Source: Based on Fawcett, Lane, & Boardman 2000

Francis (2004) shows that for all greenhouse gas emissions from domestic energy use, on a National Accounts basis, individual emissions for one, two and three plus person households are in the ratio 100:71:41. This is similar to the ratios in Table 6.6. Equivalent data for land travel show that individual emissions for one, two and three plus person households are in the ratio 100:115:85. Unfortunately air travel data are not collected by household size. Putting the land travel and household energy use data together gives a combined individual emissions ratio for one, two and three plus person households of 100:81:52. Unless people living alone fly very much less than those in larger households, it is likely that average total personal greenhouse gas and carbon emissions reduce with increasing household size.

There is little doubt that people living alone would face a greater challenge in adapting to carbon rations than those in larger households. In the UK, 29% of households contained just one person in 2003 (National Statistics 2004a). Single person households consist of a wide variety of people from a low-income widowed elderly person to an affluent young professional. The likelihood of living alone increases with age, with 48% of those over the age of 75 living alone, compared with 15% in the 45-64 year old age group in Great Britain in 2002 (Rickards et al. 2004). The environmental impacts of single person households are wider than just increased per capita carbon emissions, and affect the nation as well as the individual. People living alone are also likely to consume more land, goods and materials per person than those living in larger households (Williams 2003). Liu et al. (2004) state that rapid increase in household numbers and resultant higher per capita resource consumption in smaller households pose serious challenges to biodiversity conservation. This is not a problem just for the UK. Growth in household numbers globally, was more rapid than aggregate population growth between 1985 and 2000 (Liu et al. 2004). However, household size is typically seen as outside the realm of government policy, and the government appears to be unaware of or unconcerned by the possible environmental implications of an increase in one-person households (Williams 2003). Whether the exclusion of household size from public policy can be maintained in the face of the importance of this issue for national carbon emissions, as well as the greater difficulties under carbon rationing for people living alone, is open to question.

6.6.5 Domestic energy use carbon emissions by age of property

Figure 6.7 shows the annual energy consumption of pre-1996 and post-1996 houses in Johnston's BAU and Demand Side scenarios. The figures for pre-1996 represent the average house in the stock which was built before 1996, and post-1996 values represent the average house built from 1996 onwards. The two ages of housing use very different amounts of energy throughout the whole period, with post-1996 households in the BAU scenario generally needing only half the energy of the pre-1996 households (while achieving higher internal temperatures up to 2040). This difference means that, for example, in DJ-BAU post-96 houses make up 29% of the stock by 2050 but only use 16% of total household energy. There is a similar ratio of energy use of 2:1 between pre-96 and post-96 housing in the DJ-DS scenario, where huge strides are made in improving the energy efficiency of pre-96 housing.

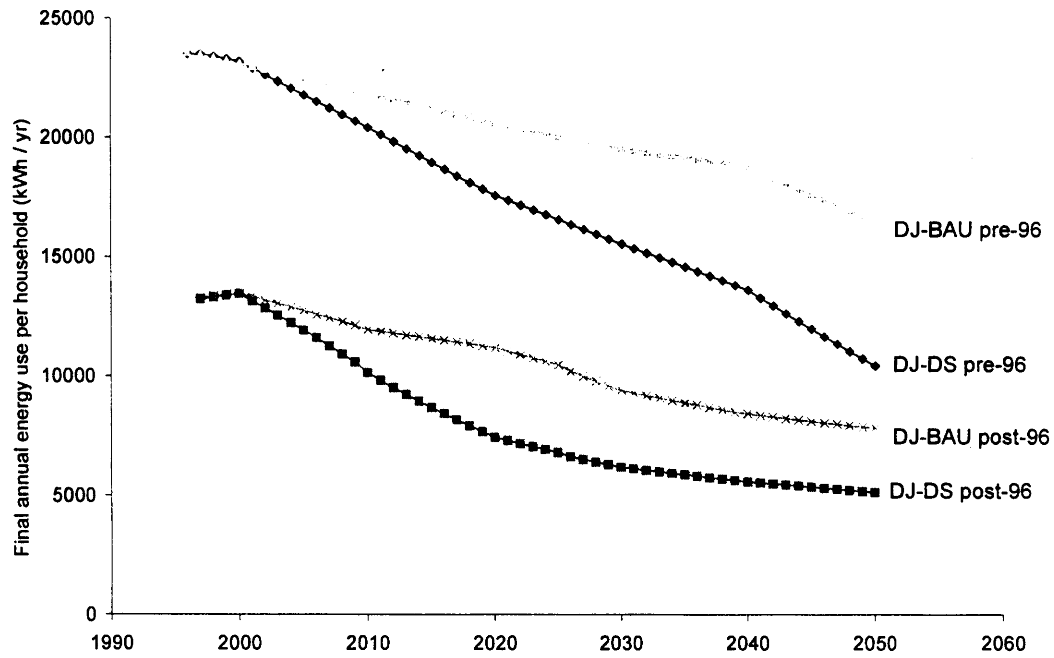

Figure 6.7: UK domestic sector annual energy consumption per pre-1996 and post-1996 household, DJ-BAU and DJ-DS, 1996-2050

The data in Figure 6.7 are a simplification of the differences that would actually emerge between different types of houses. Using just two types of houses for modelling purposes hides the variation between the best and the worst in the stock, and those which are more or less capable of upgrading to the average standards suggested in DJ-DS. In addition, in Chapter 4, doubt was thrown on some of the technologies used particularly in retro-fitting improvements to existing homes in DJ-DS. However, this analysis shows that even under optimistic assumptions about retro-fitting technology options, it is clear that differences between efficient and inefficient properties will persist through time, making it easier for people in some properties to achieve lower carbon emissions than others.

6.6.6 Greenhouse gas emissions by UK region and age of head of household

Francis (2004) investigated the variation of greenhouse gas (GHG) emissions by UK region and by age of the head of household. As explained earlier, both the methodology for counting emissions and the inclusion of greenhouse gases other than carbon dioxide means this analysis is on a different basis from that in this thesis. Nevertheless, the results can act as a proxy for the carbon dioxide emissions from fossil fuel use. All Francis' results have been adjusted so that air travel emissions reflect their true global warming impact – i.e. air travel emissions have been multiplied by three.

Regional analysis showed that GHG emissions for household energy use plus land and air travel varied little per person between England, Scotland and Wales. English emissions were equal to the UK average, with Scottish emissions being 2% higher and Welsh emissions being 6% lower. The English regions showed greater variation, with emissions in the highest region, London, being 12% higher than the average, and the emissions in Yorkshire were the lowest regional value at 17% less than average. Emissions per individual from Northern Ireland were 25% higher than the UK average – a considerable difference. However, there is good reason to believe that this is an overestimate. In carrying out his analysis, Francis has assumed that all expenditure on fuels other than gas and electricity is on coal (in common with the analysis in this thesis and that by Ekins and Dresner, he makes extensive use of the Expenditure and Food Survey). In reality, the most important fuel other than gas or electricity is heating oil (DTI 2004a), which has considerably lower carbon intensity than coal (Table 2.2). Thus GHG emissions from household energy use have been overestimated, and this is particularly the case for Northern Ireland, where natural gas has only recently been introduced and most people use 'other' fuels as their main heating source (Boardman and Fawcett 2002).

Francis also carried out analysis of household GHG differentiated by the age of the head of the household. This has been combined with GB data on the size of households by age of the head of household from the Family Resources Survey (DWP 2002). This combination results in the figures in Table 6.7. The data show interesting differences in patterns of energy use, with older households travelling much less by land and by air than younger ones, but having higher domestic energy emissions. Consequently households with a head aged 65 or over have the same emissions per person as those headed by people 30-64. Younger households have higher emissions, and these are dominated by air travel. However, given the previously identified weaknesses of air travel data, it would be best to view these figures somewhat cautiously.

Table 6.7: Greenhouse gas emissions per person by age of head of household, UK, 2001

Age	**Household size**	**Domestic energy use (tCe)**	**Land travel (tCe)**	**Air travel (tCe)**	**Total (tCe)**
Under 30	2.2	0.5	0.4	1.0	1.9
30 to 64	2.8	0.6	0.4	0.4	1.4
65 and over	1.7	0.9	0.2	0.2	1.4

Based on: Francis 2004 with adjustments to air travel figures as explained, DWP 2002

6.6.7 Summary and discussion

Table 6.8 presents a summary of the characteristics that will influence personal carbon emissions, based on the research presented in this chapter and Chapter 4.

Table 6.8: Characteristics which influence personal carbon emissions

	Low	**Personal carbon emissions** →		**High**
Main heating + hot water fuel	Wood, solar water heating or other renewables	Gas	Oil	Coal / solid fuel Electricity
Heat loss of building fabric	Low			High
Size, age and form of property	Small, new, flat or terraced	Average, mid 20th century, semi-detached		Large, old, detached / bungalow
Use of household energy	Careful, modest temperatures + warm clothes			Profligate, many gadgets, high temperatures
Travel patterns	Short distances, few or no flights			Long distances, by car, many flights
Income	Low			High
People per household	Four +	Three	Two	One
Age of head of household			Greater than 30	Less than 30

The differences identified here according to individual, household and housing characteristics are key to understanding the very different emissions between individuals found in the case study data.

The overlap between the author's research and that subsequently published by Ekins & Dresner and Francis has been useful in a number of ways. First of all, in investigating the variation of energy use by income, Ekins & Dresner have used largely the same data sources and methods of analysis as the author. This confirms the validity of the methodology used in this thesis. Secondly, both Ekins & Dresner and Francis have identified the same problems of data availability, particularly with regard to air travel. This is confirmation that no key data sources have been overlooked in this chapter's analysis.

The author has argued that, because the analysis shows individuals in lower income deciles have lower carbon emissions than those in higher deciles on average, carbon rations would not unfairly disadvantage the poor. However, in their detailed work on household energy use by income decile Dresner & Ekins (2004a) found that average expenditure figures across deciles hide a considerable variation in energy expenditure and energy use between individuals in the same decile. Those at the 80th percentile in the lowest decile consume nearly nine times as much energy as the 20th percentile of the decile. Using their more detailed data on energy expenditure by income, they look at the effect on the lowest income households of introducing DTQs covering household energy use, transport and carbon equivalent emissions from air travel (i.e. a scheme identical to personal carbon rations). Their research shows that if DTQs were introduced, around 25% of low-income households (defined as the two lowest income deciles) would be worse off. However, if only emissions from travel and aviation were included, then a smaller proportion of low-income households would lose out, no more than 10-15%. On this basis, they suggest that domestic energy use should be excluded from DTQs/carbon rations, and instead a comprehensive programme of energy efficiency measures and incentives should be put in place. Once all houses were brought up to an efficient standard, which they estimate could take 20 years, they imply then energy taxation could be introduced because fuel poverty would have disappeared.

The variation of expenditure between individuals in the same income decile undoubtedly undermines the author's argument that a carbon ration will not adversely affect those on lower incomes. However, the alternative to rationing suggested by Dresner & Ekins (2004a) is simply a variation on a technological improvement scenario which has been thoroughly investigated in Chapters 3 and 4, and found to be at high risk of not achieving carbon savings. So although Dresner & Ekins' evidence does suggest a need for more careful investigation into supporting programmes to those low income households likely to lose out under carbon rationing, the author would argue that it is still the fairest proposal which is likely to be effective in securing carbon savings. Section 6.8 will present a comparison with carbon taxation.

6.7 Objections to carbon rationing

Objections to carbon rationing, many of which have been raised at presentations and in discussions, are discussed here. In Appendix 11 there is a record of audience questions or comments made at a number of presentations about carbon rationing and contraction and convergence given the author, alone and with Mayer Hillman. One of the most common themes is the large gap between the world as it is now and the changes which would needed before carbon rationing would be adopted - this has already been discussed in Chapter 5. Other themes are discussed in turn below. These are: how will people cope?; the problems of cold winters; individual responsibility; and the role of goods and services within carbon rationing. The larger-scale strategic issues which have been raised at public meetings, such as the role of nuclear power, the nature of political and social change and the power of corporate interests, are not discussed here as they are beyond the scope of this thesis.

6.7.1 How will people cope?

One of the big concerns about carbon rationing is how people will cope with this new method of restricting their energy use. A key question is what would happen if people ran out of their ration before the end of the year - would this mean that they ended up being unable to heat their homes, and suffer ill-health or worse?

This question can be answered in a variety of ways. Firstly, because carbon rationing would become an important part of everyday life, it seems reasonable to suggest that people would swiftly learn to manage their ration. In order to be able to afford energy throughout the year, people already have to manage their money. Help and support is available for those who have difficulties with affording their energy bills (including measures such as debt counselling and pre-payment energy meters), and parallel services could be available to those who found managing their carbon ration problematic. There would have to be mechanisms in place to allow people access to vital energy services whilst at the same time recovering the carbon 'debt' over time. Energy companies might be required to offer carbon management services for vulnerable individuals who could not cope with the budgeting and trading of emissions required. Alternatively, Starkey & Anderson (2004) have suggested that individuals not wishing to participate in rationing and trading could immediately sell all their ration when it was allocated, keep the money to one side, and simply use it to buy rations on the market when they bought energy.

Another answer to this concern is that because carbon rations are tradable, there is no absolute limit on an individual's consumption and, if people could afford it, they could simply buy more carbon rations to meet their needs. They could also invest in efficiency measures etc. to reduce their carbon emissions.

Finally, it is important to remember that a lot of carbon emissions come from activities which are not nearly so vital (or as emotive) as using energy to stay warm in winter. For example, over one fifth of land-based travel in the UK (by distance) is for the purpose of seeing friends and another fifth is used for shopping, sport and entertainment (DfT 2003c). While no doubt important socially, reducing travel for these purposes would not be a matter of life and death.

6.7.2 Changes in heating energy requirements with weather

How will carbon rationing allow for the variation of heating energy requirement with different external temperatures? Data presented in earlier chapters on energy consumption in the domestic sector since 1970 (e.g Figure 3.3) clearly show that energy use can vary quite considerably from year to year. In the 1990s the coldest year was 1996, with an average temperature over the six coldest months (January to April, November and December) of 5.1°C, compared with average for the decade of 6.4°C (DTI 2004a). Domestic sector energy consumption in 1996 was 10% higher than the average of the two years either side. Carbon emissions from the household sector account for around half of personal carbon emissions, so an increase in household emission of ten percent would equate to a five percent increase in total personal emissions. According to research into climate futures (Hulme, Turnpenny, & Jenkins 2002), there are likely to be fewer cold winters in future years, as well as generally increasing temperatures. Nevertheless, there is no guarantee that there will not be any years which are cold enough to lead to a ten percent rise in energy use in future.

A carbon rationing scheme could be adapted to allow either universal or targeted additional emissions in cold years. This would necessarily result in reduced allowances for warmer years so that the overall carbon reduction target could be met. The government used to operate a cold weather payment system, giving extra money to vulnerable groups to meet increased energy costs, which was triggered by cold weather periods. In recent years this has been changed to an annual winter fuel allowance for all vulnerable groups, whatever the weather (DWP 2004). Experience shows that it has been possible to create administrative systems that respond to the weather and, if this was thought necessary, a carbon rationing system could make allowance for cold winters.

6.7.3 Putting all the responsibility on the individual

It can be argued that carbon rationing puts all the responsibility for carbon emissions from personal energy use onto the shoulders of individuals. However, manufacturers, energy companies, retailers, house builders, plumbers and many other professions and industries have an influence on a householder's or traveller's carbon emissions. For example, the carbon intensity of electricity is very largely controlled by government and the energy industries, yet it would be the householder who faces the consequences. In addition, as many authors argue, consumption is a social rather than an individual process (Shove 2003). Would the many other actors in the process which translates an individual's desire for energy or travel services into carbon emissions avoid their share of responsibility under personal carbon rationing?

The concern about individuals being expected to take responsibility where they have only limited autonomy is clearly legitimate. However, at the same time individual choices are very important in determining and potentially reducing carbon emissions, and giving the individual no responsibility would not be a viable option. While technology choices can be mandated by government, individuals and households make key choices about the ownership and use of technologies. For example, the government can make efficient boilers compulsory, but it cannot regulate thermostats in people's homes or determine their heating patterns. Under carbon rationing, manufacturers and retailers should compete to sell low carbon emissions products and all of society and its economic processes should be re-oriented towards low carbon solutions. The government will wish to support people in their choice of lower carbon options. Thus, although the individual has to manage his or her own carbon ration, it will be in the other actors' best interests to enable people to make low carbon choices, and the government would be expected to support the vulnerable. So, the view that carbon rationing places all the responsibility on the individual is incomplete. Carbon rationing is one part of a wider realignment towards a low carbon society, in which all actors will be involved.

6.7.4 Problems with not including goods and services

One of the concerns about not including goods and services is that people will not be directed towards making lower carbon goods choices, such as preferring vegetables grown in the UK to those air freighted from abroad. However, at present there are nowhere near sufficient data to be able to identify embodied energy or emissions in particular consumer goods. There are no comprehensive UK data on the indirect energy content / carbon emissions of goods and services. Francis (2004) does include some data on GHG emissions for broad ranges of goods, e.g. 'clothing and footwear' and 'food, drink and tobacco'. Somewhat more detailed data are available from the Netherlands (Wilting & Biesiot 1998). Gathering the necessary data would be far from easy, and Appendix 6 includes a discussion of the difficulties involved in compiling embodied energy data.

For the reasons elaborated in Chapter 5, it is proposed that personal carbon rations should not apply to the embodied energy in goods and services. When the equivalent of carbon rationing is introduced for the non-domestic sectors it will result in a reduction in the carbon intensity of goods and services, and householders' indirect carbon emissions will fall. Higher carbon goods and services will become more expensive relative to the lower carbon alternatives. The consequence will be that individuals will have access to a carbon emission allowance for energy on an egalitarian basis, but their access to the goods and services attached to embodied carbon emissions will depend on price and income.

6.7.5 A single nation solution?

The question of whether it would make sense for the UK to introduce carbon rationing unilaterally has been raised. As Chapter 5 stressed, ultimately UK carbon emission reductions only make sense within a global agreement to reduce carbon emissions. The UK already has adopted a unilateral target of 60% emissions reductions and, following this lead, introducing carbon rationing in the UK alone would not be a departure from current policy. However, it should also be a government priority to seek an effective post-Kyoto framework for global emissions reduction.

In this thesis, carbon rationing is proposed for the UK alone and there is no detailed discussion about its applicability to other countries. It could be equally appropriate in other developed countries, but no work has been done to explore this assumption.

6.7.6 Conclusion

While these objections or perceived weaknesses of carbon rationing (and others mentioned in Appendix 11 but not addressed here) do require a response, none of them challenges the fundamental basis of rationing. The following section looks at a completely different policy approach: carbon taxation.

6.8 Carbon taxation

6.8.1 Introduction

There are two key alternatives to a policy of carbon rations: a package of policy measures primarily focussed on energy efficiency, or carbon taxation. Chapters 3 and 4 have already argued that the first approach would be very unlikely to make the required carbon savings. Despite significant improvements in the energy efficiency of the UK housing stock, energy savings have not been achieved. The other alternative is carbon taxation, which is considered in some detail in this section. First of all the advantages of carbon taxation are explained. Then existing UK carbon and energy taxes are described. The potential levels of taxation which would be required are discussed. Finally carbon taxation is compared with carbon rations and conclusions are drawn.

6.8.2 The case for carbon taxation

Carbon taxation represents an alternative method of reducing carbon emissions from personal energy use. It would operate by increasing the price of energy such that consumption would reduce to the extent required. Like carbon rationing, it is a policy tool which provides a framework which should encourage lower carbons solutions, such as energy efficiency and renewable energy, and discourage profligate use of energy.

RCEP (2000) suggested that taxation should be part of the package of measures used to reduce the UK's carbon emissions. Their key arguments in favour of taxation were:

- it would encourage a shift to low-carbon and non-carbon energy sources;
- it would increase the average cost of energy, which would lead to reduced energy use as the attractiveness of energy saving measures and equipment increased.

They recognised this could cause problems for those in fuel poverty, but stated this should not prevent the introduction of carbon taxation, rather that comprehensive and effective compensatory mechanisms for the fuel poor should be put in place.

There are a number of other arguments in favour of carbon taxation. Firstly, it would fit well with existing administrative systems, under which energy taxation is long-established. This contrasts with carbon rationing, which would require a whole new administration and regulatory system. Carbon taxation is a policy instrument for which there is already experience: six European countries have already introduced carbon taxes (The Royal Society 2002). In addition, taxation is also considered to be an economically efficient way of making carbon savings (The Royal Society 2002).

6.8.3 Existing energy and carbon taxation

Energy taxation has long been part of UK taxation strategy. Additional energy taxation was introduced in 2001 for electricity, gas and other fuels for the non-domestic sectors of the economy via the Climate Change Levy (Chapter 2). However, levels of taxation have proved particularly controversial for both household energy and transport fuels.

In 1994, the UK government added VAT to household fuels at the rate of 8%. This was an extremely controversial move, due partly to public concern about the impact on poorer members of society. When the Labour government was elected in 1997, they reduced VAT on domestic fuels to 5%. Because of a desire not to exacerbate fuel poverty the present UK government has made a repeated commitment not to further tax the household use of energy (HM Treasury 2002).

Transport taxes, both on fuels and vehicles, are used extensively by UK governments. In September 2004, 73% of the price of petrol was taken as tax (AA 2004). The most celebrated transport tax in the UK was the 'fuel duty escalator' or fuel tax, which was introduced in 1993 to rise annually at above the rate of inflation. It was removed from government policy in 1999, and the following year much of the country was brought to a halt for several day due to 'fuel tax protests' which were inspired by claims that UK fuel taxes were higher than those in other EU countries. In the aftermath of the protests, the Chancellor pledged in his following budget to cut fuel duty by four pence per litre. However, during autumn 2003 the government once again raised tax on fuel, to little apparent public alarm. Given the seemingly inconsistent response of public opinion to fuel taxation levels, it is difficult to draw a clear lesson on the acceptability of fuel taxation.

There have been several attempts to introduce a carbon / energy tax at an EU level (Haigh 1996). This has been opposed, due to worries about the regressive nature of the tax and its potentially damaging effect on international competitiveness. In addition, many member states believed they should be free to control their own tax levels. It currently seems unlikely that there will be a co-ordinated EU-wide tax which affects domestic and transport energy use

There is no significant taxation of aircraft fuels anywhere in the world (SDC 2004a). This is something which many believe should be remedied as a matter of urgency (e.g. SDC 2004a, Bishop & Grayling 2003). As RCEP state: *"It is not acceptable that the aviation industry should continue to receive what is in effect a large subsidy at the expense of other modes of transport or sectors and the environment."* (2002: 32)

6.8.4 What level would taxes be set at?

There does not appear to be a study on carbon taxation which looks at what level of taxation would be required to reduce carbon emissions by 60% by 2050. This is not perhaps surprising as the methodology usually used for calculating the effects of future taxes, using elasticities of demand, is not designed for taxes which would be much greater than those in previous experiences and which will be employed for decades into the future.

Price elasticity of demand describes how demand for energy changes with price. If an 8% increase in price reduced demand by 2%, the resultant elasticity would be -0.25. In addition to this there is income elasticity of demand, a measure of how demand for energy changes as income changes. Finally, another important factor is how demand for different fuels will vary with their relative prices (known as cross-elasticity). So a forecast of energy demand in the year 2020 must take into account all of these factors:

"it will need a price-elasticity-of-demand-in-2020-assuming-that-all-other-energy-prices-are-unchanged, and so on." (Ramage 1997: 339)

Barker, Ekins, & Johnstone (1995) concluded that measurements of price elasticity are beset with theoretical problems and that different measurement techniques result in different numbers. Also, the future under climate change will be so different from the past that even if current measurements of elasticity were meaningful and reliable (which they may not be) then they may offer no guide to a future where many things may be very different. If the authors are correct, then it is simply not possible to state (now) what taxation levels will need to be in order to reduce emissions sufficiently.

However, others take a different view. RCEP (2000) report work undertaken for the DTI's Energy Advisory Panel, which estimated that the carbon tax required to bring about a 20% reduction in emissions by 2010 would cause a 72% increase in domestic gas prices and a 23% increase in domestic electricity prices (compared to a 1990 base year). RCEP suggest this level of price rise would be unacceptable and stress that carbon taxation should only be introduced as part of a wider package of measures.

6.8.5 Comparison of carbon taxation with carbon rations

Table 6.9 summarises comparative characteristics of carbon taxation and carbon rations. The statements in this table are elaborated below.

Table 6.9: Summary of comparison between carbon rations and carbon taxation

Characteristics	**Carbon rations**	**Carbon taxation**
Basis for introduction	Equal rations for all.	Emissions determined by ability to afford energy cost + tax.
Distributive effects (i.e. effects on different income groups)	Progressive	Progressive for road and air transport. Regressive for household energy.
Administrative system	New system would have to be introduced.	Already in place.
Effectiveness	Guaranteed to deliver savings.	Savings will depend on the economy, taxation rates will have to continually adjusted to deliver savings.
Economic efficiency	Both policies are economically efficient.	
Political acceptability	Both face severe challenges to acceptance. Carbon rationing may be more acceptable as a long term solution.	

Carbon taxation operates on a different basis from carbon rationing. It allows those with higher incomes to pollute more as of right, rather than sharing a scarce resource equally. However, it could be designed to penalise high consumption levels. Nevertheless, because of the nature of taxation, it is unlikely to engender the same 'all in it together' social cohesion towards the goal of lower carbon emissions as could rationing based on equal carbon shares.

The poor spend a higher proportion of their income on household energy than the rich (see data in Appendix 10). Thus, carbon taxation is regressive, i.e. those on a lower income would be left proportionally worse off by its introduction than those on higher incomes. Supporters of carbon taxation in the domestic sector argue that the poor can be compensated for its effects, either through the benefits and taxation system or by introducing progressive tariffs such that basic energy needs can be afforded by everyone, with luxury levels of consumption being more expensive (SDC 2004b). However, as argued earlier, it may be very difficult if not impossible to make an acceptable distinction between 'needs' and 'luxury'. In addition, Ekins & Dresner (2004) concluded that it is not possible to adequately compensate the fuel poor for the effects of domestic energy carbon taxation. The question of whether lower income groups really could be compensated for the effects of carbon taxation is far from settled.

The effectiveness of carbon taxation varies according to the trade cycle — a tax rate that achieves its objective in a period of strong economic growth will be much too harsh when that same economy is in recession (Meyer 2000). This means there would need to be continual amendments to carbon taxation to ensure the necessary carbon savings were achieved. By contrast, rationing has the advantage of certainty of result: it is clear exactly what carbon savings will be made.

One of the benefits of increased carbon taxation is that the administrative system needed to ensure this occurs is already in place, whereas a new system would be needed to introduced carbon rations (as discussed in Chapter 5).

Carbon taxation is considered to be an economically efficient way of making carbon savings. A recent report suggests this may also be the case for carbon rationing: *"In principle, tradable permits achieve the same result as environmental taxes....In practice, there are several considerations that may favour one option over the other."*(The Royal Society 2002:11) The report focuses on firms rather than individual householders and the effect of introducing tradable permits (like rations or DTQs) for householders, rather than carbon taxes, is not discussed. However, the conclusion is that in theory there are no economic grounds for favouring taxes compared with rations.

There are good reasons to believe that the massive carbon taxation necessary to reduce emissions by 60% or more would be less politically or socially acceptable than the incremental introduction of a system of personal carbon rationing. Chapter 5 presented arguments suggesting that without equal rights to carbon emissions, there is little prospect of a global agreement on emissions reduction. These arguments can be equally made on a national level, where the prospects of introducing a carbon reduction scheme on other than an equitable basis may be equally poor. In addition, recent history suggests that it is likely there would be great resistance to any form of taxation on household energy use or on petrol and diesel

In conclusion, although carbon taxation may have some short-term benefits, such as policy familiarity and ease of administrative introduction, carbon rationing is more likely to introduce a carbon cap that has clarity, certainty of result, equity for individuals and likelihood of implementation.

6.9 Summary and conclusions

This chapter began with a discussion in principle of whether giving people equal carbon emissions could really be described as equitable. This is because equity is one of the key claimed benefits of carbon rations, along with certainty of savings. The conclusion is that while it will not be perfectly fair, it is the fairest possible system. Attempts to design an alternative allocation system based on differentiating 'needs' and 'wants' would end in failure.

Original case study data on personal carbon emissions have been presented. Very powerful insights have emerged from this sample of thirty two people. The most striking finding is the range of carbon emissions encountered, with the highest carbon emissions being twelve times the lowest. Compared with the average UK carbon emissions for personal travel and household energy use, the lowest emissions in the survey were 37% of the average, with the highest being 4.6 times the average. Highly unequal individual contributions to climate change are being made at present in terms of direct energy use. Another surprising insight is the extent to which patterns of carbon emissions differ, with the ratios of household: land travel: air travel emissions varying widely.

This variation shows that the trading aspect of carbon rations will be very important to many people, who may not want to change their lifestyles drastically, and who need to buy spare rations. The problem of trading and vast differences between individual requirements did not arise under food rationing (Chapter 5). In addition, many different adaptation strategies will be necessary depending on individual circumstances. One size will not fit all.

As well as differences between individuals, the systematic differences between various groups have been explored. Expenditure data has been used to show that individual carbon emissions for household energy use and personal private transport increase with income decile. Analysis has shown that people in one-person household use considerably more household energy per person than those in multi-person households. Others likely to have higher than average emissions are: households headed by an under-30 year old; users of solid fuel and oil heating; those living in large, detached or inefficient houses; frequent flyers and high mileage car users; and those who prefer very warm rooms to warm clothing. Use of the model developed in Chapter 4 shows that the energy consumption differences between old and new homes is likely to persist through time, even if considerable technical improvements are made to existing old houses.

A number of problems with carbon rationing, some of which were identified at public meetings, have been discussed. Each of these objections to rations is discussed in turn. Although each highlights potential practical or theoretical objections to introducing carbon rations, in the author's view none is powerful enough to merit fundamentally re-considering the proposition that carbon rationing would be a good policy solution to delivering 60% or greater carbon savings by 2050.

Finally, carbon rationing is compared with one of the major alternatives – carbon taxation. Research does not indicate how high carbon taxation would have to be to achieve 60% savings by 2050, indeed it may be impossible to do so given the methodology available. Carbon taxation is a much more familiar policy than carbon rations and would have some administrative advantages. However, this chapter has argued that carbon taxation would provide neither the same advantage of certainty of result nor the same moral justification as a system of carbon rationing. Introducing carbon rations is unlikely to be easy, universally popular or without problems. However, this applies equally to the alternative of carbon taxation on the scale likely to be required to make significant savings. It is hard to imagine carbon rations being introduced given today's political and social priorities. However significant carbon savings are not going to be made if the world continues in a 'business as usual' mode. If we are serious about preventing serious climate change, there is no choice but to challenge the status quo in a fundamental way.

Chapter 7 – Discussion and conclusions

7.1 Chapter overview

The central aim of this thesis has been to identify a plausible route to achieving 60% carbon savings in the UK domestic sector by 2050, and in particular to investigate whether strategies relying on either energy efficiency or personal carbon rations are likely to be successful. In undertaking the research, many different types of evidence and analysis have been employed, from detailed investigation of energy savings from solar water heaters, to a critique of government energy policy.

This chapter pulls together the key evidence from each of the preceding chapters which supports the conclusions reached. Linkages between different parts of the research and findings from different chapters are emphasised. Chapter 1 provided background information, demonstrating why the thesis question is important. Chapter 2 presented information and analysis regarding energy consumption and carbon emissions in the UK, particularly in the domestic sector. Chapter 3 and 4 were primarily concerned with answering the question of whether energy efficiency had in the past, or was likely in the future, to deliver significant energy savings. The answer was that it was not. Following this, Chapter 5 focussed on making the case for carbon rationing as an effective policy mechanism for making 60% savings. Chapter 6 investigated its weaknesses as well as strengths. Overall, this analysis leads to the conclusion that personal carbon rations offer a more convincing route to sufficient carbon savings than reliance primarily on energy efficiency improvements.

Following the summary of research findings, there is reflection on the methodologies used to undertake the research. Areas for further research and unanswered questions are identified, and suggestions for changes to government data gathering and policies are made. Finally, the original contribution to knowledge made by this thesis is clearly outlined.

7.2 Key research findings

Figure 7.1 is a reminder of the three key themes of the thesis: understanding the true challenge of 60% savings; investigating whether a strategy of largely relying on energy efficiency is likely to be effective; and developing and critically evaluating the idea of personal carbon rations. Key research findings are here presented under these three headings.

Figure 7.1: Overview of thesis structure

Context: Identifying the true challenge of achieving 60% savings.	**Chapter 1:** Climate change and the global context **Chapter 2:** The UK's contribution to climate change and the role of the domestic sector. Identifying emissions not currently counted.
Question 1: Is a strategy of relying largely on improvements in energy efficiency likely to achieve the required savings?	**Chapter 2:** The effects of efficiency policy on energy consumption since 1970. **Chapter 3:** Modelling savings from efficiency: past experience, current practice and pitfalls **Chapter 4:** Identifying the potential of social change to outstrip technological means to deliver efficiency savings.
Question 2: Could personal carbon rations offer an alternative route to savings?	**Chapter 5:** Introducing carbon rations, explaining the principles and practical details. **Chapter 6:** Critically evaluating carbon rations, investigating their effects on individuals and different social groups, comparing with taxation.
Chapter 7: Discussion and conclusions	

7.2.1 The true challenge of achieving 60% savings by 2050

Chapter 1 concluded that despite a global response to climate change, in the UNFCC and Kyoto treaty, there have been few actions by any governments which truly recognise the scale of action required to prevent "dangerous anthropogenic interference with the climate system".

Chapter 2 focussed on the UK's record on carbon dioxide emission reductions. This has been challenged, and found to be less good than it at first appears. In spite of rising energy demand, emissions have fallen considerably since 1970 and the UK is likely to be one of the very few nations to meet its Kyoto reduction targets. However, firstly, most of the carbon savings are a result of changes towards lower carbon fuels, which cannot be repeated in future. Hence the UK is not as firmly on the path towards a low carbon economy as this statistic suggests. Secondly, when the carbon equivalent effect of international airline emissions are taken into account, UK emissions have not fallen since 1990. Including international air travel adds 19% to UK carbon emissions for 2002. Thirdly, preliminary evidence suggests that the UK has exported (net) energy-intensive activities to other countries, meaning that the indirect energy use of imports exceeds that of exports. Together these factors indicate that the UK will have to work harder to achieve future emissions because fortuitous reductions will not happen on the same scale again. It also shows that achieving a 60% reduction on the UK's 'real' carbon emissions (i.e. including the carbon equivalent emissions of all air travel) will be more challenging than the current understanding which excludes the fastest growing source of emissions.

In conclusion, the challenge in reducing the UK's carbon dioxide emissions is much greater than generally thought.

7.2.2 Can energy efficiency deliver 60% savings?

The government's current strategy for making carbon savings in the domestic sector up to 2020 relies primarily on energy efficiency, with a minor contribution from renewable energy and CHP (DTI 2003b). In Chapters 2, 3 and 4, evidence for the effectiveness of energy efficiency in delivering energy savings in the domestic sector has been reviewed. The arguments in favour of relying primarily on energy efficiency together with the counter-arguments presented in this thesis are summarised in Table 7.1.

Table 7.1: Arguments for and against the proposition that 60% carbon savings can be achieved by 2050 largely through improvements in energy efficiency

Arguments for believing that energy efficiency can achieve 60% savings by 2050	**Counter-arguments and evidence presented in this thesis**
Past policies have achieved energy savings, compared with what would have happened in the absence of efficiency measures.	Considerable improvements in energy efficiency in the domestic sector over the past thirty years have not led to actual energy savings. Despite a 30% decrease in heat losses from buildings, and a 43% improvement in space heating efficiency, average energy use per household has not decreased over the past thirty years, due to a contemporaneous increase in demand for energy services. Because of increasing household numbers, total energy use in the domestic sector rose by 32% between 1970 and 2001. (Chapter 2)
Considerable savings from efficiency are still available. UK modelling studies summarised in Chapter 3 show a range of potential energy savings from the domestic sector between 1995/2000 and 2020 of between 13% and 25%. Two studies (Johnston 2003a, ICCEPT 2002) show 60% carbon savings being achievable by 2050.	Studies like this have also been produced in earlier decades, but the savings have not materialised. These studies assumed widespread adoption of existing energy efficient technologies, the development of new technologies, and limited growth in demand for energy services. These expectations have not been met – and current modelling and scenario exercises are likely to be just as vulnerable to these type of assumptions not being met in reality as those in the past. (Chapter 3)

	Monitoring evidence shows real life savings from specific policies and measures are often lower than those projected by models. (Chapter 3) Johnston's Business As Usual (DJ-BAU) projection underestimates future energy demand, and thus overestimates the ease of using technical improvements to achieve a 60% reduction in carbon emissions. While Johnston's projection for energy use 1997-2003 was constant, in actual fact energy use has risen. (Chapter 4) Modelling of potential energy savings has several weaknesses which leads to an over-estimation of potential savings. (Chapters 3 + 4) Even with very vigorous technological improvements, plausible increases in energy use due to increasing demand could far outweigh reductions due to efficiency. The High Energy scenario (TF-HighE) shows 58% greater energy use in 2050 than in DJ-BAU. If this is combined with the technological savings in DJ-DS, a maximum of 17% energy savings would be achievable by 2050. (Chapter 4)
New technologies offer new savings opportunities, e.g. micro-CHP.	The key energy saving technologies have not changed in thirty years. (Chapter 3) New technologies, e.g. mains pressure hot water, digital entertainment equipment, which could facilitate increases in energy usage have however grown and are identified. (Chapter 4) Non-technical issues could prevent energy saving technologies being adopted, for example the problems of creating a market and aesthetic concerns could prevent widespread uptake of solid wall insulation. (Chapter 4)
With very robust policy and actions, past experience can be transcended and efficiency can lead to savings.	Scenario analysis argues that only with a society-wide change towards sustainability will major carbon and energy savings be achieved. (Chapter 3) The new government policies planned to make savings to 2010 (DEFRA 2004b) offer little different from previous policies which have improved efficiency, but not saved energy. Current energy policy in the domestic sector barely engages with questions of consumption, despite the fact that increased demand for energy services has been a key force in moving energy consumption upwards. (Chapters 2 + 4)

The conclusion is that, while efficiency can deliver savings in theory, these are only likely to be realised if there is a cap on increasing energy demand. Without this, this thesis has argued that improvements in energy efficiency are very unlikely to result in significant energy savings. Therefore, relying on energy efficiency to deliver unprecedented sector-wide savings in energy is too risky given the serious nature of climate change, and an alternative strategy is required.

7.2.3 Investigation and critical analysis of personal carbon rations

Chapter 5 introduced the idea of carbon rationing as a mechanism to achieve a cap on carbon emissions, and situated it within the existing literature. Calculations have shown that personal carbon equivalent emissions, from household energy use and all forms of transport (including by air), account for 51% of UK national emissions.

The key advantages of carbon rationing are:

- It offers an overall framework for carbon savings, which can incorporate and encourage savings from energy efficiency, renewable energy, social change and lifestyle alterations.
- It would be equitable, based on egalitarian interpretation of equity, giving individual carbon allowances.
- It fits with the international scheme, contraction and convergence.

The practicalities of introducing carbon rationing have also been discussed in some detail:

- The experience of food rationing during the second world war shows it is possible to introduce a successful UK-wide rationing system.
- The global agreement to protect the ozone layer, offers a positive example of a global environmental treaty which has some of the features a future climate agreement will need.
- Introduction of carbon rations would need to be supported by considerable government information and education campaigns. Many methods of providing information about personal carbon rations have been identified, these include carbon labels for appliances, carbon receipts for petrol, intelligent energy meters.
- There would also be many opportunities for businesses and other organisations to help consumers live within their ration, including ideas such as 'CarbonWatchers'.
- Administratively, carbon rationing should pose no great problems, as electronic transactions are standard for most people, and the number of businesses selling fossil fuel energy sources direct to the public is relatively low. However, that is not to say there are no challenges, for example, several million people currently do not have bank accounts and may be unfamiliar with electronic transactions.

A strong case has been made for carbon rationing as a practical policy, and the beginnings of support for and research into carbon rationing and similar schemes has been reported.

Chapter 6 took a more critical look at carbon rationing as an idea, and presented original analysis and data to illuminate further what the introduction of carbon rationing might mean in practice. Key findings from the original and secondary data were:

- Equal carbon rations would not lead to equal energy consumption or equal energy services for individuals because of differences in energy types, efficiency of use and lifestyle choices. For example, equal carbon allowances for heating could result in a difference of six and half degrees in the internal temperature achieved in the same house, depending on fuel used and efficiency of the heating system.
- Case study data has shown that currently there is a highly unequal distribution of personal carbon emissions between people in the UK, with a factor of twelve difference between the thirty-two people in the sample.
- The case studies also demonstrate the varying composition of carbon emissions – with very different balances between household energy fuels, personal transport and international air travel. This will make adaptation to carbon rationing very different between individuals.
- Analysis of individual carbon emissions by household income decile has shown that personal carbon emissions rise with income, when land travel, air travel and household energy use emissions are all included.

A number of problems with carbon rationing were identified, but none was persuasive enough to merit rejecting carbon rationing as a solution. Finally, carbon taxation was considered as an alternative to carbon rationing. Carbon taxation would have the advantage of familiarity and ease of implementation. However, the disadvantages include the fact that carbon taxation would be regressive (would affect those on lower incomes more than those on higher incomes), would have to be constantly adjusted to achieve the necessary carbon savings and would not have the same moral basis as carbon rationing.

In conclusion, a case has been made for personal carbon rations as a means of achieving 60% savings by 2050, which warrants more detailed investigation (as suggested in Section 7.5).

7.3 Reflection on methodology

A variety of methods have been used to address the research questions in this thesis. The success, limitations and contributions of different methodologies are addressed below.

Original analysis of secondary data was a key part of the research in this thesis. Existing national data was required to get new insights into energy use and carbon emissions. Results included identifying the contribution of international air travel to the UK's carbon and carbon equivalent emissions, calculating the percentage of UK carbon equivalent emissions that are generated from personal energy use and travel and estimating the carbon emissions from different income deciles of the population. Making use of existing national statistics has also led to suggestions for additional data which should be collected or compiled by the government (Section 7.5).

Past projections of the future have been compared with what has actually happened for both bottom-up and top-down modelling. The useful insights from this analysis make the case for more historical awareness and reflection on past experience in energy research, as a means of enriching understanding.

In Chapter 3, the inherent problems of using a model to look forward almost fifty years were identified. Nevertheless, an existing bottom-up model was replicated in Chapter 4, in order to highlight how vulnerable even well-researched technological improvement scenarios could be to plausible increases in demand for energy services. It also helped identify what savings could be achieved by reducing demand for energy services or society-wide changes such as increasing the rate of demolition. Modelling was useful in order to challenge projections for energy savings through efficiency on their own terms.

There is a lack of interaction between different types of futures modelling. As Chapter 3 demonstrated, scenario exercises suggest that decreased emissions will only happen in futures which give increased priority to sustainability. However this result is ignored by bottom-up modelling which assumes technology change can be implemented and make emissions savings whatever the societal and economic environment. Having made this criticism, the modelling in this thesis has only addressed it to a limited extent. This is because the model was primarily used to show grounds for disputing the results of bottom-up modelling on its own terms, rather than trying to create a better type of modelling.

Original empirical data have also been used in this thesis, and they have proved to be valuable, despite its limited scope. The collection of a small number of carbon audits, although just a pilot study, proved to be very illuminating. In retrospect, more effort might have been spent on this aspect of the work, by trying to collect data over time, or focusing on particular groups. In addition, the feedback received from public presentation of carbon rationing was helpful in identifying concerns about carbon rationing. This was particularly the case in the virtual absence of a literature on carbon rationing and related ideas. Although this feedback was not as systematic as an academic review of carbon rationing might be, it brought to light a very wide range of comments and concerns.

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7.4 Limitations of this research

One of the key limitations of this research is that the thesis subject is multi-disciplinary, but most of the author's analysis has been technical and policy-oriented. This thesis contains little qualitative data or social science-based analysis, or economic analysis which would have added to the arguments around carbon rationing, and especially the comparison with carbon taxation. Energy policy is by its nature a multi-disciplinary area of enquiry and ideally such problems are best tackled by multidisciplinary teams, which is not possible within a PhD where individual research is required.

Although the thesis question concerns only energy use in the household sector, the research has exceeded these boundaries. Firstly, to understand the full picture of carbon emissions in the UK, international air emissions had to be investigated and incorporated into the total. Secondly, to research carbon rations it was necessary also to include personal transport emissions. The disadvantage of widening boundaries is the risk that the research goes beyond the author's area of expertise. Every effort has been made to undertake high quality research in these areas, and the author benefited from working with a transport expert, Mayer Hillman on parallel research, as explained in Chapter 1. Nevertheless, widening boundaries poses risks as well as offering benefits.

Other specific limitations are:

- The Tina Fawcett (TF) model used in Chapter 4 suffers from several limitations, which include modelling just two standard house types, an inability to include new uses of energy, and incomplete understanding of the linkage between efficiency and behaviour.
- Carbon emissions data gathered from the thirty-two individuals did not include the actual emissions from their car travel (national averages were used) so underestimated the true extent of variation between individuals.
- Most of the analysis of carbon emissions by different groups relied on proxy data.
- Analysis of the effects of carbon rations on individuals by income decile did not acknowledge the wide variations in energy use between individuals in the same decile.

7.5 Recommendations for further research

The recommendations for further research are outlined under several separate headings below.

7.5.1 Technical and modelling research

In Chapter 4 a number of questions were identified as being difficult to answer due to a lack of technical data. The following technical and modelling issues would benefit from further research:

- Monitoring energy savings from solar water heating in 'real life' situations and agreement on the format for reporting savings from such systems
- Better monitored data on hot water usage and investigation of the possible effects of the new combi and mains pressure hot water systems on patterns of demand
- More monitoring of internal temperatures in housing
- Research on the potential for and problems with solid wall insulation – including non-technical concerns around markets and aesthetics
- Adjusting UK degree day data to take account of climate change
- Creation of population density-weighted heating season figures for expected temperature changes under UK future climate scenarios.

7.5.2 Gathering further data on individual carbon emissions

Chapter 6 presented pilot data on individual carbon emissions. However, a much better understanding of the variations in carbon emissions between individuals and households would be essential before carbon rationing could be introduced.

Collection of additional data would need to be done in two stages:

1. Developing the methodology for determining carbon rations

This thesis used a deliberately simplified methodology with which to estimate individual carbon emissions. However, to get more precise information on individual carbon emissions it would be necessary to develop the methodology further.

2. Large-scale survey of current individual carbon emissions

The data from a nationally-representative survey would be used to advance the understanding of carbon emissions from different groups within society. This could be based on one of the existing household energy or travel surveys.

Some of the topics which could be investigated with such data include: identifying groups who would be disadvantaged under carbon rationing, e.g. one-person households; discovering whether people's emissions can be fitted into a number of characteristic patterns, for which different advice on carbon reduction possibilities would be required; understanding children's carbon emissions patterns. Appendix 12 discusses a future research agenda for carbon rationing in further detail.

7.5.3 Social science research

Social science-based analysis would be very important in investigating the potential role of carbon rations. Two examples of research which could be undertaken are given below:

- Experience during this research has been that many people, even those who would claim to be environmentally concerned, seem reluctant to calculate their own carbon emissions (Chapter 6). Face-to-face interview and focus groups could be used to try and characterise further and gain insight into the roots of this reluctance.
- To try to understand how people might adapt to carbon rationing, they could be introduced to the idea and asked to imagine how they would respond to future rations. This might reveal which aspects of people's energy use are least negotiable, and what actions they would take first in order to reduce their carbon emissions – and how these decisions would vary between individuals. The outcomes would be limited by people's ability to predict their own behaviour in the unfamiliar scenario of energy rationing. However the results would provide an insight into the social challenges associated with carbon rationing.

7.5.4 Economic questions

Economic questions which require further investigation include:

- What would happen to the price of fuel under conditions of carbon rationing but no shortage of supply?
- Is it possible to create an estimate of how much carbon taxation would have to rise to achieve 60% reductions in emissions by 2050?
- How should the trading aspect of carbon rations be introduced, and what would be the fairest and most effective way of running the trading element of the scheme?
- Identifying the sort of businesses and activities that would thrive under a low carbon regime.

7.6 Recommendations for policy makers

Recommendations are made for changes to national policy, international policy and the availability and presentation of government data.

7.6.1 National policy

The key policy recommendation from this research is that the UK government should seriously explore carbon rationing for personal energy use. Initially, more research on carbon rationing is required to understand in more detail how the policy could work and how it would affect people.

In order to prepare for a lower carbon future, the government should introduce education and information measures to help the public understand the carbon consequences of their choices. Chapter 5 identified many possible measures, including altering the information which appears on energy labels on lights and appliances at the point of sale, including carbon information on energy bills, and public education campaigns. Whether or not the government eventually introduces carbon rations, these education and information measures will be an essential part of achieving 60% savings by 2050.

Possible tensions and contradictions in the goals of the government's energy policy have been identified (Chapter 2). The key question is whether economic growth is consistent with reducing carbon emissions. There needs to be a policy review to identify the many conflicts between different parts of the government's policy, building on the work the Sustainable Development Commission (SDC 2003) has already undertaken on sustainable economic growth and alternative measurements of well-being.

7.6.2 International policy

The UK needs a negotiating strategy for achieving a global carbon reduction framework beyond Kyoto. Without this its 60% target for 2050 will lose its meaning as a contribution to preventing maximum atmospheric concentrations of CO_2 exceeding 550ppm. This thesis suggests that contraction and convergence is the only framework which is likely to be successful and that the UK government should adopt it unilaterally.

Given the recent reports that IPCC may have underestimated the climate changing effects of concentrations of carbon dioxide in the atmosphere (Chapter 1), the Royal Commission on Environmental Pollution should re-consider whether 550ppm is a sufficiently risk-averse upper limit on atmospheric concentrations of carbon dioxide. This would lead also to consideration of whether a 60% reduction by 2050 would be sufficient to avoid 'dangerous climate change' (the stated aim of the UN Framework Convention on Climate Change (United Nations 1992)).

Finally, the government should try to advance international agreement on the apportioning of carbon and carbon equivalent emissions from international air transport, so that this can be included in the successor to the Kyoto agreement.

7.6.3 Improvements to government data

Analysis in this thesis has relied heavily on government data. In the course of this research, gaps in data provision and potentially confusing data have been identified, and this section makes recommendations for improving the provision of government data.

The following data were either missing or difficult to extract from existing publications:

- Carbon dioxide emissions by sector (up to date) – the most recent data are for 2001
- Carbon dioxide intensity of electricity (up to date) – the most recent data are for 1999. The carbon intensity of electricity is not published with the main energy statistical series, the Digest of UK Energy Statistics, but instead can be found for 1990-1999 in a one-off document (DEFRA 2001a).
- Aircraft emissions – both national and international have been difficult to find.
- UK total carbon dioxide emissions including international air transport, both as carbon and carbon equivalent emissions.

Recommendations

- All the data identified above should be included clearly in annual government publications.
- As the fastest growing source of carbon dioxide, international air travel emissions should be included in UK environmental indicators as a matter of urgency, without waiting for an international agreement on accounting for international air movements.
- Publishing airline emissions without acknowledging the greater degree of radiative forcing due to aircraft emissions verges on the misleading. Data should be published both in terms of tC and tCe (based on the best current scientific understanding of the radiative forcing effect of emissions in the upper atmosphere).

Finally, carbon dioxide data for the UK are available based on three different methodologies – IPCC, UNECE and that used for the National and Environmental Accounts. A degree of complexity is no doubt inevitable given different international reporting requirements. However given the importance of carbon dioxide and greenhouse gas emissions, the government has a duty to make the figures as transparent and accessible as possible. More could be done to compare and contrast the results from the different methodologies and to make clear which data set should be used for different purposes. If IPCC is the 'main' methodology, government studies which report based on other bases (e.g. Francis, 2004) should explain how their results would differ if IPCC methodology had been used.

7.7 Original contribution to knowledge

This thesis has made a number of original contributions to knowledge:

- UK carbon equivalent emissions have been calculated when international aircraft energy use is included. This gives a new insight into the reality of UK carbon emissions and highlights the importance of international air travel.

- The proportion of carbon and carbon equivalent emissions for which individuals are directly responsible has been identified.
- A bottom-up energy use model, developed by Johnston, has been replicated and minor flaws have been corrected. The model has been used to investigate the vulnerability of savings from technological improvements to plausible increases in demand for energy services.
- A wide variety of data has been used to demonstrate that it is very unlikely that a strategy based primarily on energy efficiency will result in significant savings from the domestic sector.
- The idea of carbon rationing has been developed in considerable detail. Practical aspects of the policy have been discussed, as have possible routes to easing the introduction of carbon rationing.
- Objections to carbon rationing have been collated and addressed.
- Original case study data on the personal carbon emissions of individuals have been presented. The data demonstrate the wide range of individual carbon emissions, even within the small pilot study group, and the striking degree to which the activities which lead to emissions can vary between people.
- There has been an initial analysis of the effect of carbon rationing on different groups within society, particularly different income groups.
- Recommendations have been made for further research and changes to the way government data on carbon and carbon equivalent emissions are presented.

The results of the research have been disseminated via conference and journal papers (Fawcett 2002, Fawcett 2003, Fawcett 2004) and in the book co-authored with Hillman (Hillman & Fawcett 2004). In addition, parts of the work have been presented at public meetings (as listed in Appendix 11) and at various university seminars and teaching sessions. Evidence based on this research and the work with Hillman has also been submitted to two UK and one EU enquiry into related topics (e.g. Fawcett & Hillman 2004).

7.8 Were the objectives of my thesis achieved?

This thesis aimed to identify a means for achieving 60% savings in the domestic sector by 2050. Initially, the generally accepted solution of energy efficiency was investigated and was found to be at high risk of not delivering savings. Thus carbon rationing has been proposed as an alternative strategy. This could in principle achieve 60% savings (or any other level that the ration was set to achieve). To build the case for carbon rationing, it has been important to go beyond setting out principles and to show how it might work in practice. Suggestions have been made about how present policy could be transformed to work under carbon rationing. In summary the true challenge of meeting a 60% target has been identified, the conventional solution of energy efficiency has been disputed, and a good initial case has been made for carbon rationing and its likely effectiveness. Therefore the objective of the thesis has been achieved.

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Appendix 1: Comparisons of future-oriented house designs

This appendix compares two 'self-sufficient' houses – designed and built about 20 years apart. The reason for the comparison is to see how architects and designers with approximately the same objectives resolved the problem of making a house largely self-sufficient, or autonomous. The self-sufficiency was primarily focussed on energy, although both houses also addressed other resource issues. Both projects aimed to demonstrate methods of more sustainable future construction. This is explicitly acknowledged in the name of the first: 'a house for the future'. The book documenting the second house, 'the new autonomous house', states: "Robert and Brenda Vale provide a thought-provoking, practical solution to the environmental problems caused by the houses in which we live, a blueprint of green architecture for future generations".

'A house for the future' was adapted from an existing building in Macclesfield and occupied in 1976. It was the focus for a television series (McLaughlin 1977). 'The new autonomous house' was newly built on a site in a small town, Southwell, Nottinghamshire and occupied in 1994 (Vale & Vale 2000). Both houses were detached family homes with gardens. The key technologies and approaches used in each house are summarised below (Table A1.1). There are both similarities and differences between the houses. The documentation for the 1970s house is not as comprehensive as that for the later house, so detailed comparisons are not always possible.

Table A1.1: Comparison of two future-oriented houses built twenty years apart

Technologies and approaches used	A house for the future, 1976	The new autonomous house, 1994
Solar water heating	Yes- 'open' low-efficiency system, where water does not run in pipes installed over whole of south-facing roof (45m2).	No – electricity used instead as SWH thought 'too expensive'. Hot water demand was reduced considerably from UK norm.
Solar PV	No – 'too expensive'	Yes – provided 1600 kWh in first year, 52% of household requirements.
Wind turbine	Installed but problematic – still not working well after one year	No
Active solar space heating	Using excess hot water from roof plus storage –judged not to have been very successful	No
Passive solar design	Large windows facing south, small facing north. Also greenhouse with heat store on south side of building.	Adopted only to a limited extent due to site constraints. Conservatory attached to south-west wall.

Back-up heating system	Solid fuel boiler	Wood burning stove.
Ventilation and heat exchange system	Yes – successful	Yes – operated only when required. Mostly operates by natural air leakage.
Insulation	Yes – judged the most critical part of improvements.	Yes
Efficient lights and appliances	No – but did have a large pantry for food storage – not clear whether this replaced some refrigeration.	Efficient lighting, but most appliances were already owned – possibly inefficient. Appliance ownership restricted.
Embodied energy	Not mentioned (would be less of an issue as house not built from new.)	Key consideration – heavy materials sourced locally.
Sewerage	Not stated.	Composting toilet – which has had only minor problems. Other 'greywater' discharged to soakaway – which has been more problematic.
Water supply	Not stated	Rainwater collected from the roof, stored and treated for use. No other water supply
Vegetable and fruit plot	Yes	Yes

It is also possible to make some comparisons of the U values (a measure of insulating performance, where lower number indicate greater resistance to heat transfer, i.e. better insulation) for elements in the two houses (Table A1.2). For comparison, standards in the Building Regulations 2002 (elemental method) and possible future standards in 2005 are presented.

Table A1.2 House element U values (W/m^{2}K)

Building element	**U value (W/m^{2}K)**			
	A house for the future, 1976	**New autonomous house, 1994**	**Building regulations, 2002**	**Possible standards, 2005**[1]
External wall	0.3	0.14	0.35	0.27
Roof	<0.3	0.07	0.16-0.25	0.13
Glazing (average)	Not stated – double glazing	0.85 Triple glazing – low E	2.0-2.2	1.8
Floor	0.36	Not insulated as basement underneath	0.25	0.22

Sources: ODPM 2001, ODPM 2004

[1] The 2005 Part L building regulations will require achievement of a target carbon emissions rate per square metre (TCER). Standards are no longer specified in terms of U-values. However if these values are achieved, the building should meet the TCER.

The most interesting similarities between the houses are:

- The key role of insulation
- Use of mechanical ventilation and heat recovery systems
- The 1994 new autonomous house did not incorporate any technologies which were not available in some form in 1976.

The most interesting differences are:

- The different view taken of solar PV and solar water heating. PV has become considerably cheaper since the 1970s, although it is still expensive, at around £10,000 for a system capable of generating 1,500 kWh/ year. Solar water heating is generally thought to be the better value option, but by reducing hot water demand the Vales judged the economics were not in its favour.
- The improvement in technologies is noticeable – particularly insulation values achievable in walls, windows and doors (Table A1.2).
- Due to climate change concerns, coal would not now be used in a back-up heating system for a low energy home.
- The 1994 house employed fewer renewable energy technologies now than were used in the 1976 house. Active solar heating and wind turbines are not generally considered viable now.
- Due to energy labelling, people can now make choices about the efficiency of their appliances and boilers, which was not possible until the 1990s.

The comparison does show that insulation and some renewable energy technologies have improved since the 1970s. However, it also clearly illustrates that there have been no new 'wonder' technologies. Indeed, time has proved that some technologies being tried in the 1970s, such as active solar heating, are not viable despite the hopes at the time. Perhaps the most sobering reflection is the slow progress in bringing the ideas tried out in the 1970s house into the mainstream, so that in the 1990s it was still necessary to be building demonstration homes with advanced insulation and other long-established energy saving technology.

The comparison of the advanced homes' U-values with those mandated in 2002 and expected to be introduced in 2005, shows that 2002 standards for new houses were similar to those achieved in 1976 for a retro-fit project. The standards achieved in the new autonomous house are higher by a considerable margin than those in the 2002 regulations and 2005 proposals, showing there is room for future improvement of building standards.

Appendix 2 – BREDEM based model

These calculations, based on BREDEM and SAP, are used within TF model to calculate energy consumption of the housing stock, for each type of housing for each year 1996-2050.

1. Weighted average overall building dimensions

Total floor areas, m^2		(5)
Dwelling volume, m^3		(6)

2. Weighted average ventilation rate

Infiltration due to chimneys, fans and flues		(10)
Measured $L_{50} \div 20$ + infiltration due to chimneys, fans and flues		(19)
Shelter factor	0.85	(21)

(Assumes that 2 sides of the 'notional' dwellings are sheltered)

IF dwelling has mechanical ventilation with heat recovery

Effective air change rate = shelter factor x [($L_{50} \div$ 20) + infiltration due to chimneys, fans and flues] + [($1-\eta_T$)x 0.5] (22)

Where η_T is the efficiency of heat recovery, taken as 66% throughout and 0.5 is the design air supply rate. Where heat recovery is absent, η_T is zero and the equation becomes...
effective air change rate = shelter x [($L_{50} \div$ 20) + infiltration due to chimneys, fans and flues] + 0.5

If dwelling is naturally ventilated

Background ventilation rate = shelter factor x [($L_{50} \div$ 20) +infiltration due to chimneys, fans and flues] (23)

If background ventilation rate >=1, effective ventilation rate = background ventilation rate

Otherwise ventilation rate = (1+background ventilation rate^2) $\div$ 2		(24)
Weighted effective air change rate		(25)

3. Weighted average heat losses and heat loss parameter

ELEMENT		Area (m^2)		U-value (W/m^2K)		A x U (W/K)	
Doors			x		=		(26)
Windows	0.9x		x		=		(27)
Ground floor			x		=		(30)
Walls			x		=		(31)
Roof			x		=		(33)
Fabric heat loss C_t = (26) + (27) + (30) + (31) + (33)							(33a)

* the factor 0.9 takes into account the normal use of curtains

Ventilation heat loss, C_v = weighted average effective air change rate x 0.33 x dwelling volume (36)

Total heat loss $Q_T = C_t + C_v$		(37)
Heat Loss Parameter, HLP (W/m^2K) = $Q_T \div$ total floor area		(38)

4. Weighted average water-heating energy requirement

Hot water energy requirement, HWER = mean household size x annual hot water demand x 45*		(39)
* assumes that cold water enters at 10C and is supplied to the hot water tap at 55C		
Distribution loss DL		(40)
Energy lost from hot water storage tank, HWSTL		(43)
Weighted solar input = solar fraction x proportion of dwellings with solar		(47)
Primary circuit loss, PCL		(48)
Output from water heater = HWER + DL +HWSTL + PCL- solar input		(49)
Efficiency of water heater (%)		(50)
Energy required for water heating = [output from water heater x 100] ÷ efficiency of water heater		(51)
Heat gains from water heating, W = {(0.25 x HWER) + [0.8 x (DL + HWSTL + PCL)]} x 31.71		(52)

5. Weighted average internal gains

	Watts	
Lights, appliances, cooking and metabolic		(53)
Heat gains from water heating		(52)
Total internal gains = Lights, appliances, cooking & metabolic gains + heat gains from water heating		(55)

6. Weighted average solar gains

For the solar gains calculations it is assumed that all of the glazing on the 'notional' dwellings is orientated on the north and south face. The ratio of south to north glazing is defined as the 'asymmetry'

	Area (m^2)		Flux (Table A2.1)		Gains (W)	
Windows (m^2)						(56a)
Asymmetry					1.00	(56b)
Orientation						
North facing solar gains = area of glazing x 0.5 =		x		=		(56c)
South facing solar gains = area of glazing x 0.5 =		x		=		(60)
Total gains from glazing = North facing gains + south facing gains						(64a)
Solar access factor (assumed to be 1 for notional dwellings)					1.00	(65)
Solar gains = total gains from glazing x solar access factor						(66)
Total gains, W = total internal gains + solar gains						(67)
Gains/ loss ratio, GLR = total gains ÷ Q_T						(68)
Utilisation factor = 1-exp[-18 ÷ GLR]						(69)
Useful gains = total gains x utilisation factor						(70)

7. Weighted average mean internal temperature

	°C	
Mean internal temperature, T_{in}		(77)

8. Degree days

	°C	
Temperature rise from gains, ΔT_{free} = Useful gains ÷ Q_T		(78a)
Temperature rise due to global warming, $\Delta T_{global\ warming}$		(78b)
Base temperature = T_{in} - ΔT_{free} - $\Delta T_{global\ warming}$		(79)
Degree days DD (use box (79) and Table A2.2)		(80)

9. Weighted average space-heating energy requirement

	GJ/year	
Energy requirement (useful) = 0.0000864 x DD x Q_T		(81)
Conventional heating systems		
Fraction of heat from secondary system		(82)
Efficiency of main heating system, %		(83)
Efficiency of secondary heating system, %		(84)
Weighted average space heating fuel, main = [1.0 – (82)] x (81) x 100 ÷ (83)		(85)
Weighted average space heating fuel, secondary = (82) x (81) x 100 ÷ (84)		(86)
Community heating		
Overall system efficiency	100	(82*)
Distribution loss factor (Table A2.3)		(85*)
Space heating from district heating = [((81) x 100) ÷ ((82*) x (85*))] x proportion of dwellings with community heating		(87*)

10. Weighted average cooking energy requirement

	GJ/year	
Electric cooking		(88)
Gas cooking		(89)

11. Weighted average lighting energy requirement

	GJ/year	
Lighting requirement		(90)

12. Weighted average appliance energy requirement

	GJ/year	
Consumer electronics		(91)
Wet goods		(92)
Cold goods		(93)
Miscellaneous goods		(94)
Electricity for MHVR		(95)

13. Total weighted average energy requirement per 'notional' dwelling

	GJ/year	
Space heating = (85) + (86) + (87*)		(96)
Water heating = (51)		(97)
Lights = (90)		(98)
Appliances = (91) + (92) + (93) + (94)		(99)
MVHR system = (95)		(100)

Cooking = (88) +(89)		(101)
Total = (96) + (97) + ...(101)		(102)

Table A2. 1: Solar flux through glazing

	Flux (W/m2)	
	North	South
Single glazed	13	32
Double glazed (air or argon filled)	11	28
Triple glazed (air or argon filled)	10	25

Source: adapted from BRE 2001

Table A2.2: Degree days as a function of base temperature

Base temperature	Degree days	Base temperature	Degree days
1.0	0	11.0	1140
1.5	30	11.5	1240
2.0	60	12.0	1345
2.5	95	12.5	4150
3.0	125	13.0	1560
3.5	150	13.5	1670
4.0	185	14.0	1780
4.5	220	14.5	1900
5.0	265	15.0	2015
5.5	310	15.5	2130
6.0	360	16.0	2250
6.5	420	16.5	2370
7.0	480	17.0	2490
7.5	550	17.5	2610
8.0	620	18.0	2730
8.5	695	18.5	2850
9.0	775	19.0	2970
9.5	860	19.5	3090
10.0	950	20.0	3210
10.5	1045	20.5	3330

Source: BRE & DETR 1998

Table A2.3: Distribution loss factor for group and community schemes

Heat distribution system	Factor
Mains piping system installed in 1990 or earlier, not pre-insulated, medium or high temperature distribution (120 – 140°C), full flow system	1.20
Pre-insulated mains piping system installed in 1990 or earlier, low temperature distribution (100°C or below), full flow system	1.10
Modern high temperature system (up to 120°C), using pre-insulated mains installed in 1991 or later, variable flow system	1.10
Modern pre-insulated piping system operating at 100°C or below, full control system installed in 1991 or later, variable flow system	1.05

Source: BRE 2001

Appendix 3: Summary of TF scenarios

These tables summarise input and output values from three scenarios: TF-BAU, TF-LowE and TF-HighE.

Table A3.1: Summary of TF-BAU scenario inputs

	Pre-1996 1996	Pre-1996 2050	Post-1996 1997	Post-1996 2050
Households:				
Total number of UK households (million)	24.010	22.260	0.243	9.184
Mean household size	2.4	2.0	2.4	2.0
Dwelling size:				
Floor area (m^2)	85	83	76	83
Volume (m^3)	212.5	207.5	174.8	190.9
Building fabric:				
Wall U-value (W/m^2K)	1.40	0.96	0.45	0.24
Ground floor U-value (W/m^2K)	0.67	0.62	0.45	0.20
Roof U-value (W/m^2K)	0.50	0.43	0.25	0.14
Glazing U-value (W/m^2K)	4.04	1.62	3.30	1.61
Door U-value (W/m^2K)	3.70	1.51	3.30	1.61
Air leakage rate (ac/h @ 50Pa)	13.1	12.4	11.7	5.4
Total dwelling heat loss (W/K)	287.7	194.0	144.9	80.7
Mean internal temperature:				
24 hour mean internal temperature	16.0	21.0	18.0	21.0
Space and water heating systems				
Efficiency of primary space heating system (%)	66.6	85.9	78.6	87.9
Efficiency of secondary space heating system (%)	60.0	77.5	68.2	81.1
Efficiency of water heating system (%)	71.7	87.2	79.9	87.2
Hot water usage per person (litres/day)	42.9	40.0	42.9	40.0
Lights, appliances and cooking (per dwelling):				
Lighting consumption (kWh/year)	704	841	709	841
Cold appliance consumption (kWh/year)	728	301	725	301
Wet appliance consumption (kWh/year)	473	262	471	262
Consumer electronics consumption (kWh/year)	437	719	431	719
Miscellaneous appliances consumption (kWh/yr)	232	209	232	209
Gas cooking consumption (kWh/year)	347	277	343	277
Electric cooking consumption (kWh/year)	530	481	528	481

Table A3.2: Summary of TF-BAU outputs

	UK domestic sector, annual final energy (TWh)				
	Space heating	Water heating	Lights & appliances	Cooking	Total
1996	354	125	62	21	561
2000	361	123	63	21	569
2010	449	117	70	21	657
2020	446	110	76	22	654
2030	375	102	79	23	579
2040	326	97	80	25	527
2050	267	89	77	25	459

Table A3.3: Summary of TF-LowE scenario inputs

	Pre-1996 1996	Pre-1996 2050	Post-1996 1997	Post-1996 2050
Households:				
Total number of UK households (million)	24.010	19.700	0.243	1.985
Mean household size	2.4	2.9	2.4	2.9
Demolition rate (thousands / yr)	16.6	162	16.6	162
Dwelling size:				
Floor area (m^2)	85	80	76	76
Volume (m^3)	212.5	200	174.8	174.8
Building fabric:				
All values as per TF-BAU				
Mean internal temperature:				
24 hour mean internal temperature	16.0	16.0	18.0	16.0
Space and water heating systems:				
All values as per TF-BAU, except...				
Hot water usage per person (litres/day)	42.9	20.0	42.9	20.0
Lights, appliances and cooking (per dwelling):				
Lighting consumption (kWh/year)	704	421	709	421
Cold appliance consumption (kWh/year)	728	360	725	360
Wet appliance consumption (kWh/year)	473	131	471	131
Consumer electronics consumption (kWh/year)	437	151	431	151
Miscellaneous appliances consumption (kWh/yr)	232	104	232	104
Gas cooking consumption (kWh/year)	347	139	343	139
Electric cooking consumption (kWh/year)	530	241	528	241

Table A3.4: Summary of TF-LowE outputs

	UK domestic sector, annual final energy (TWh)				
	Space heating	Water heating	Lights & appliances	Cooking	Total
1996	354	125	62	21	561
2000	351	129	63	21	565
2010	271	109	61	20	460
2020	210	87	52	17	366
2030	166	66	43	14	289
2040	133	52	34	11	230
2050	102	40	25	8	175

Table A3.5: Summary of TF-HighE scenario inputs

	Pre-1996 1996	Pre-1996 2050	Post-1996 1997	Post-1996 2050
Households:				
Total number of UK households (million)	24.010	23.121	0.243	11.800
Mean household size	2.4	1.8	2.4	1.8
Demolition rate (thousands / yr)	16.6	16.2	16.6	16.2
Dwelling size:				
Floor area (m^2)	85	80	76	76
Volume (m^3)	212.5	200	174.8	174.8
Building fabric:				
All values as per TF-BAU				
Mean internal temperature:				
24 hour mean internal temperature	16.0	23.0	18.0	23.0
Space and water heating systems:				
All values as per TF-BAU, except..				
Hot water usage per person (litres/day)	42.9	80.0	42.9	80.0
Lights, appliances and cooking (per dwelling):				
Lighting consumption (kWh/year)	704	1682	709	1682
Cold appliance consumption (kWh/year)	728	1438	725	1438
Wet appliance consumption (kWh/year)	473	524	471	524
Consumer electronics consumption (kWh/year)	437	602	431	602
Miscellaneous appliances consumption (kWh/yr)	232	418	232	418
Gas cooking consumption (kWh/year)	347	554	343	554
Electric cooking consumption (kWh/year)	530	962	528	962

Table A3.6: Summary of TF-HighE outputs

	UK domestic sector, annual final energy (TWh)				
	Space heating	Water heating	Lights & appliances	Cooking	Total
1996	354	125	62	21	561
2000	348	136	63	21	569
2010	347	139	77	25	587
2020	351	141	97	31	620
2030	352	141	118	38	649
2040	362	143	140	45	690
2050	338	144	163	53	699

Appendix 4: Modelling solar water heating

Introduction

Johnston includes solar water heating (SWH) in the Demand Side scenario (DJ-DS)

- pre-1996 housing - by 2050 10% of dwellings have solar water heating
- post-1996 housing - from 2010 all dwellings to have solar water heating.

So, solar water heating is an important technology for reducing the use of fossil fuels. However, the way it is currently modelled could be improved, as described below.

Energy supplied per system

Johnston's modelling of SWH is based on the concept of 'solar fraction' which can be confusing; it is usually used to indicate the percentage of hot water demand supplied by solar water heating. However, 'hot water demand' does not include the losses involved in heating hot water. A SWH providing a 70% solar fraction will not replace 70% of the energy used to produce hot water unless the non-solar hot water system is 100% efficient. Solar fraction is a concept used widely within the SWH industry – possibly because of the ambiguity of the phrase.

Because of the way hot water demand is modelled by Johnston, a constant solar fraction results in the same SWH system delivering different amounts of energy over time. Hot water energy demand changes over time in the same way in all scenarios. It is based on a slowly reducing water demand per person, from 43 litres of hot water per day in 1996 to 40 litres per day by 2050, multiplied by the number of people per household, which also decreases over time. In total, household hot water energy requirement reduces from 1961 kWh in 1996 to 1416 kWh in 2050. Johnston assumed that a solar fraction of 70% would be achievable. This is not impossible, but the more generally quoted figure is that a SWH system can provide up to 50% of annual hot water needs (EST 2003). A SWH supplying a 70% solar fraction would deliver 1370kWh in 1996 and 990kWh in 2050. Because of this inconsistency, it seems preferable to model the contribution of SWH systems as a constant amount of energy, rather than as a fraction of hot water energy demand.

In order to determine how much energy an average SWH system can deliver, data on monitored systems and other expert opinion is described and analysed below. There do not appear to be any large-scale monitoring studies of solar hot water heating in the UK. The largest study identified monitored eight different solar water heaters under test conditions. The other two studies monitored three and seven homes with SWH installed (Table A4.1).

Table A4.1: Summary of UK studies monitoring the performance of solar water heating

Study	No. of systems monitored	Annual energy delivered (kWh)	Solar fraction	Notes
ECD, Reading (Stewart 2000)	3	380 – 580	57% *	*Solar fraction defined as % total energy used to provide hot water (inc.losses).
IT Power, South Wales (IT Power 2002)	7	not stated	60%	
Martin & Watson Side-by-side testing (Martin & Watson 2001)	8	960 – 1350		Systems monitored under test conditions

Of these studies, the most useful was the Martin and Watson (2001) study, both because the monitoring was very thorough and the results were reported in full detail. Eight different SWHs were set up at a test site, both flat plate and evacuated tube systems (the two major SWH technologies). The monitoring data, collected over six months, were extrapolated to give a total annual figure for energy delivered by each SWH, based on solar irradiation at Kew facing S at an elevation of 30 degrees and varying water input temperature throughout the year. In order to measure energy delivered, 150 litres of water was drawn off daily at 55°C. This was thought to represent the energy demand of a four person household. The draw-off pattern was varied between being all taken at once and taken throughout the day, to see what difference this might make.

The range of energy delivered annually from the systems was 960 to 1340 kWh for single run-off and 1010 to 1350 kWh for a multiple run-off pattern. The energy delivered was relatively insensitive to the run-off pattern. The study also recorded the amount of electricity used by each system. Electricity consumption per system varied between 44 – 109 kWh/yr. The values in this study were for systems which were facing south, thus producing the maximum amount of energy possible.

The Reading SWH systems delivered far less energy than those in the side-by-side trial. There were a number of odd things about the monitoring data:

- Although the houses had identical SWH systems, one supplied a third less energy than the other two.
- The energy supplied by the SWH systems was only half of that predicted (the prediction was for 1,100 kWh/year).

- The houses have very low total water heating energy use – meaning that despite modest energy output from the SWH systems, it was possible to report an energy contribution of greater than 50%.

It might be that the systems for monitoring hot water use, and partitioning energy use between space heating and water were not very accurate, and the data are incorrect. However, if the data are correct, then the results raise serious questions about the credibility of the savings the equipment suppliers predicted. The author had some correspondence with the people who had commissioned the research on the three Reading systems, but unfortunately, it proved not to be possible to resolve this issue.

It was not possible to get more detailed information on the monitoring carried out by IT Power, so it is not clear what their 60% solar fraction means in terms of kWh/year.

In addition to monitored data, there are a number of estimates of the amount of energy a SWH system will typically deliver:

- the Solar Trade Association (Solar Trade Association 2003) estimates that a solar water heating system in a typical household provides energy in the form of heated water of approximately 1,000kWh to 1,500kWh per annum.
- ETSU (ETSU 1999) also estimated that for an average SWH system with a 3-4 m2 collector, between 1000 and 1500kWh of energy will be produced per year.

Given experimental data and other research, it seems that a figure of 1,200 kWh/year energy delivered is not unrealistic for a SWH located on a south facing roof. However, not all SWH can be installed on south facing roofs which are not over-shaded, and so the expected contribution of solar water heating needs to be reduced to account for this. SWHs placed on east or west facing roofs are estimated to produce 15% less energy than those on south facing roofs (ESD 2003), which would give a figure of 1020 kWh. The average figure used in the model (for the TF-BAU and TF-LowE scenarios) will be 1,100 kWh/year, which is realistic assuming that the systems installed will meet current best practice standards. In addition, based on the Martin and Watson study, it is also assumed that electricity consumption (to run the pumps etc.) will be at the low end of the current range at 50kWh/year.

Conclusions

The way that solar water heating energy is included in the model has been changed, from a solar fraction approach to a fixed contribution of 1,100kWh per SWH system. This does not greatly change the value which emerged from the 70% solar fraction used by Johnston (which varied from 1370kWh in 1996 to 990kWh). However, it does put the modelling on a more consistent basis.

Appendix 5: Demolition rates, past and present

Introduction

This appendix estimates current demolition rates in England. It also looks at the history of demolition from the 1950s onwards – as well as giving good background understanding to the current situation. Looking to the past gives indicators of the boundaries of possibility for future demolition rates.

Demolition of housing can be divided into three categories:

- Publicly-funded demolition of private housing under slum clearance procedures;
- Privately-funded demolition of (largely) private housing;
- Demolition of local authority / social housing.

By far the most significant mechanism for demolition historically has been slum clearance, but now this has been overtaken by demolition of local authority housing.

Slum clearance demolition

Slum clearance demolition, which is funded by the government and administered by local authorities, deals with 'unfit' private housing ('unfitness' is legally defined). Although local authorities have had powers to clear slum housing since the late nineteenth century these were not used on a significant scale until the clearance drive of the nineteen thirties. In 1939 houses were being demolished at the rate of about 90,000 per year (English, Madigan, & Norman 1976). After a fifteen year interruption caused by the Second World War the second clearance campaign reached its peak around 1970 at over 70,000 properties per annum (Figure A5.1). The demolition rate has declined dramatically from that time.

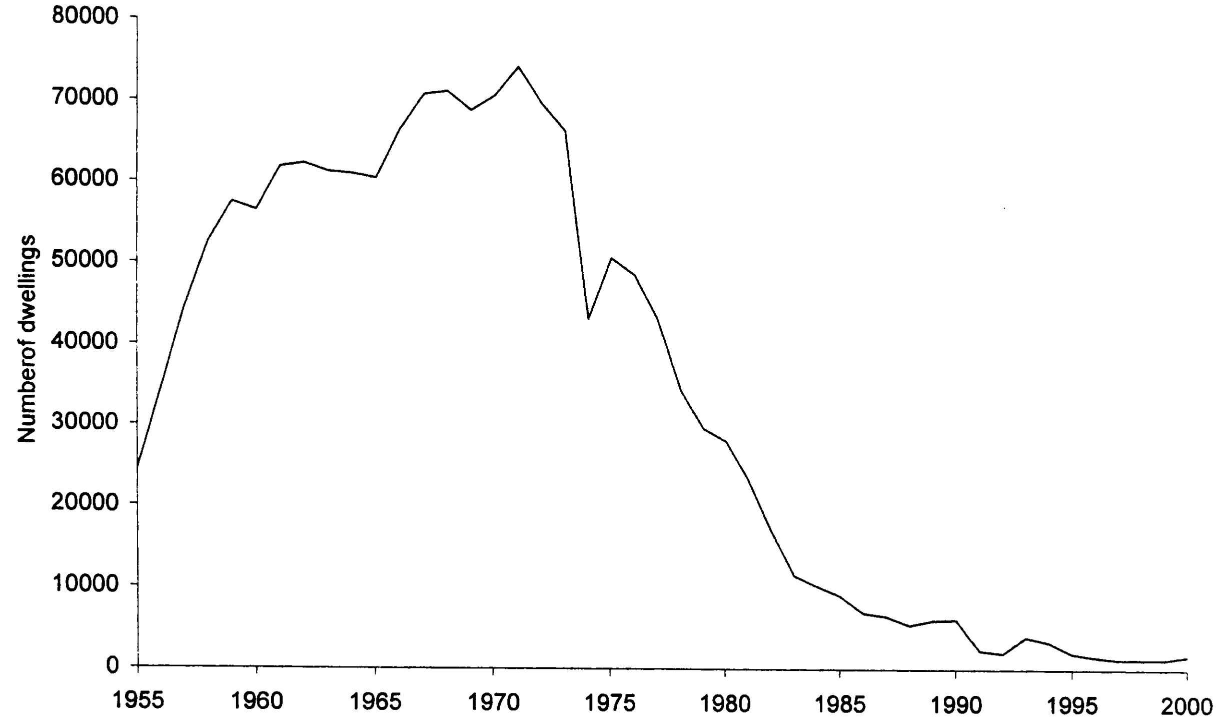


Figure A5.1: Slum clearance: dwellings demolished or closed, England and Wales, 1955-2000

Sources: 1955-1975: English, Madigan, & Norman 1976
1976-80: DoE, Scottish Development Department, & Welsh Office 1981
1981-90: DoE, Scottish Development Department, & Welsh Office 1991
1991-1997: DoE, Scottish Development Department, & Welsh Office 2000
1998-2000: DTLR 2001b - England only

Commentators suggest that the shift away from large-scale demolition was not primarily related to the improved quality of the remaining housing stock. For example, Balchin and Rhoden (1998:221) state that the decline in slum clearance demolition evolved "largely as a consequence of the difficulties posed by large-scale clearance in terms of both political and financial implications." English et al (1976:44) suggested the following factors: the unacceptable social consequences of clearance were stressed by politicians, reflecting the findings of much academic work; development of community opposition to many individual local schemes made the procedure less attractive to local officials; the then Conservative government policy encouraged alternatives to growing municipalisation of the housing stock.

Many things have changed in Britain since the last big slum clearance campaign in the 1970s. Currently 69% of the stock is owner occupied compared with 50% in 1971(DTLR 2001b). National house condition surveys in 1967 and 1971 (quoted in English et al 1976:155) showed that 73% of properties in potential slum clearance areas were owned by private landlords with the remainder being owner occupied. Thus, demolition was mainly of privately-rented, working class housing. Most people from slum clearance areas moved into council housing.

Privately-funded demolition

Demolition and rebuilding of housing (outside of the local authority stock) occurs on a minor scale without the need for government funding. Government research shows that this activity is concentrated in areas where there is a combination of houses in large plots and strong demand for flats (DETR 2000b). DETR estimate from the data available that redevelopment of private sector and housing association stock delivers a net gain of between 5,000 and 12,000 units per year and suggest it is likely that the actual rate is at the lower end of this scale. A reasonable estimate figure for the number of properties demolished might be quarter the number of new properties created, approximately 1,000 – 3,000.

Demolition of local authority stock

The number of English local authority dwellings demolished per year has increased through the 1990s from 4,300 dwellings in 1991/92 to 16,200 in 2000/01 (DTLR 2001b). These official figures are an underestimate of actual numbers demolished, according to further government research (DETR 2000c). A postal survey collected information on properties which had been sold to the private sector prior to their demolition – these demolitions are not included in the official figures. On this basis the estimate of local authority dwellings demolished in the six year period April 1991 to March 1997 was increased from the total (31,100) to around 40,000 dwellings – that is around 25% higher than previously thought.

Estimate of total current demolitions

Using government figures, including an estimate of privately-funded demolitions and increasing local authority demolitions as explained above, results in an estimate of 24,400 dwellings demolished in England in 2000/01 (Table A5.1).

Table A5.1: Estimated housing demolitions, England, 2000/01

Type of demolition	Dwellings demolished	Percentage
Slum clearance	1,700	7
Local authority	20,000	82
Privately funded	2,000	8
Change of use	500	2
Non-permanent dwelling loss	200	1
TOTAL	24,400	100

Source: DTLR 2002 with amendments as per text

This is equivalent to demolishing around 0.1% of the English housing stock per annum, i.e. houses having to last 1000 years before replacement. At this rate of demolition, 94% of houses built by 2000 will still be standing in 2050. Rates of private housing demolition are much lower at 0.02%, implying these houses will have to last for 5000 years.

Future demolition rates

The life span of buildings is not simply, or even primarily, a technical issue; political, economic and social considerations are also important. In the case of housing, the rate of demolition has been largely determined by central and local government policy and has been funded by government. But, with a largely privately-owned housing stock, who takes responsibility for ensuring the appropriate level of demolition? Past and current evidence suggests the market will not encourage owners to undertake sufficient demolition to ensure that the stock is of a socially and environmentally desirable quality. If the rate of demolition is to increase it will either require a government funded programme, or a change to the housing market rules such that houses which are of very poor environmental quality, which cannot be sufficiently upgraded, are no longer saleable. Neither of these options seems at all likely at present. Presently, it seems the UK is likely to experience very low rates of demolition, particularly in the private sector, and an ageing housing stock, for many years to come.

Appendix 6: Embodied energy in UK housing

This appendix explains the concept of embodied energy, presents data on the embodied energy in a typical UK house and discusses the reliability of the available data. The aim is to get an idea of the scale of embodied energy in a house compared with the running energy used over the life time of the house.

Embodied energy comprises all of the energy required to mine raw materials, to manufacture them into construction materials or components and to deliver and construct them on site. It is the energy which has 'gone in with the bricks' and cannot be recovered in the lifetime of the building (Sustainable Homes 1999). Energy used in house construction and demolition is often excluded from embodied energy figures, it is generally considered to be small. For example, Adalberth (1999) states that energy used in erection and demolition is around 1% of the total life cycle energy use of a house.

There are two basic approaches to embodied energy estimates for houses: bottom-up and top-down. The top-down method uses energy consumption figures in the construction industry (and its precursors) to estimate the amount of energy that is embodied in houses. The bottom-up method uses estimates of the amounts of materials used to make up a house and their typical embodied energy to come up with a total for the whole house. The bottom-up method is more detailed and is the one which is typically used. There are various methods to derive embodied energy coefficients of materials and these include process analysis, input-output analysis, statistical analysis and hybrid analysis. Process and input-output analysis have provided much of the available embodied energy data (Pullen 1996).

However, there are serious problems with embodied energy data, which can be inaccurate with wide variations in the data available for what is supposedly the same material. There are a number of factors that lead to variations in the data:

- data can be given in either primary or delivered energy, usually not stated which;
- different primary to delivered energy conversion ratios are used;
- energy for transport may or may not be included for the import of raw materials or delivery of final products;
- different product specifications are used;
- recycled materials can be accounted for differently, plus some allowance may be made for the future recyclability of the material;
- the same materials are made using different sources of fuel and different manufacturing processes;

- older estimates tend to be higher as manufacturing processes become progressively more energy-efficient (Based on: Yohanis & Norton 2002).

There is little published information on the embodied energy of a typical UK house. The table below brings together various studies on the embodied energy of UK houses. These figures are for the houses themselves, not the possessions they contain. The embodied energy is compared per square metre where possible. Unfortunately embodied energy studies differ widely in the methodology adopted, which energy components are included and whether results are presented as primary or delivered energy, and the methodology is often not given in detail in the original source.

Table A6.1: UK figures for embodied energy in houses

House description	Date	Embodied energy (1000 kWh)	Embodied energy / m^2 (kWh/m^2)	Reference
$80m^2$ brick	1976	27.8 – 50	350 - 630	Gartner & Smith (1976)
Roaf energy efficient house	1996		2,580	Viljoen & Thompson (1996)
Five different types of housing including timber + brick, $90m^2$, detached	Late 1990s	190 – 340	2,110 – 4,250	Estimated from data in Smithdale & Thompson (1998)
100 m^2 masonry	2000?	115	1,150	Strathclyde University (2002)
Current UK housing stock average	2000	180	1,800	Estimated from Rao et al. (2000) and Anderson & Howard (2000) – for details see below
detached 3 bedroom house	1998	138		Anderson, MSc Thesis unpublished, University of East London (pers comm.)
New house, detached, $160m^2$	2002	90	563	Brinkley (2002) His sources of information are not stated.

The figures per square metre vary by a factor of more than ten between the different studies. By far the most detailed work on the embodied energy of a house was published in 1976 by Gartner and Smith. However, their figures seem considerably lower than those of most other authors. Some of the more recent estimates are tending to higher totals, but this is not universally true, with Brinkley (2002) giving a low estimate of embodied energy per square metre. This variation makes it difficult to come to a consensus view of what the embodied energy in a UK house is, or how it might compare with the average annual energy use of a home.

Rao et al (2000) and Anderson & Howard (2000) use a top down method to estimate the embodied energy in a new home. They suggest that between 1 and 3% of UK total energy is consumed in the products used to construct new houses. If, say, 2% of UK energy is used to build 180,000 homes, then the embodied in the typical new UK home would be around 220,000 kWh (using DTI 2004a). This is equivalent to about ten years of energy in use for an average home (Shorrock and Utley 2003).

However, the conclusion from this brief review is that before a good estimate can be made of the importance of embodied energy in the lifetime energy costs of a house, more research is needed to untangle the many issues surrounding the understanding and use of embodied energy data.

Appendix 7: Carbon audit form

When the carbon audit form below was distributed it was printed on two sides of paper.

Climate change and you

This questionnaire is designed to find out how carbon dioxide emissions vary between individuals. Carbon dioxide emissions from fossil fuel energy use are the major cause of climate change and global warming. In the UK, half of all carbon dioxide comes from energy use in houses and from personal transport by air, train, car and bus.

For 2003, please try to estimate your personal energy use, using what information you have available. It is not important to be really accurate, just do the best you can and make estimates where necessary. Information from your questionnaire will be used anonymously and for research purposes only.

Please send completed form to: Tina Fawcett, 29 Stapleton Road, Headington, Oxford OX3 7LX, or email it to: t.fawcett@ucl.ac.uk. Any questions, please email me or phone 01865 761697.

About you

Please state your occupation:

Would you like feedback on your responses? YES / NO

If YES, your contact details (email / name + address):

Feedback will include an assessment of your carbon emissions, tips for reducing them and a comparison with the UK average. I will aim to supply this within four weeks.

Domestic energy use, 2003

You should be able to get energy use information from your household's energy bills. If this isn't possible, please estimate how much was spent on domestic energy in 2003. The important thing is you give an annual figure, not that it relates exactly to 1 Jan - 31 Dec 2003.

Gas users: gas usage is measured in different ways depending on your meter and company. The main options are kWh, cubic metres, 100s of cubic feet. If possible please report usage in kWh, or state which measurement unit you're using - if this is difficult, please include the cost of your gas usage.

	Energy use 2003	**Units**	**Energy cost 2003 (optional)**
Gas			
Electricity		kWh	
Heating oil		Litres / gallons	

If you use any other fuels, e.g. solid fuel / paraffin and can estimate in terms of cost or weight / volume how much you use per year, please give that information here.

How many people live in your household? Adults Children
(I want to know this so I can calculate your personal share of the household's domestic energy use)

Do you use off-peak electricity (Economy 7 / White Meter etc.) for heating or hot water? YES/ NO

Have you chosen a renewable electricity tariff? YES / NO

Personal transport energy use, 2003

Car travel - you only need to fill this in if you are a driver. Distance travelled as a passenger is not counted in this survey. For cars over three years old, you can use consecutive MOT certificates to find out your annual mileage. For newer cars, you can use the mileometer.

Rail / bus / air - there is table below with distances of journeys within and outside the UK. If you don't know how far you have travelled, particularly for long distance or air journeys, you can instead write down the routes you travelled last year and I'll work it out.

Include travel to and from work/ college, but not travel that you undertake as part of your job. Please state whether you are giving distances in miles or kilometres!

	Transport method	**Distance travelled 2003**	**Miles / km?**	**Route(s)**
Car	Petrol car (as driver)		Miles/km	
	Diesel car (as driver)		Miles/km	
Rail	Intercity		Miles/km	
	Other services		Miles/km	
	Underground		Miles/km	
Bus/coach	London bus		Miles/km	
	Other bus		Miles/km	
	Inter-city coaches		Miles/km	
Air	Within Europe		Miles/km	
	Beyond Europe		Miles/km	

Is there anything else you want to tell me about your household energy use or travel?

Distances for journeys inside and outside UK - All distances are return from London

UK long distance	**km**	**London underground**	**km**
Birmingham	386	Ealing Broadway/Victoria	16
Brighton	190	Edgware / Green Park	12
Cardiff	498	Mile End / Holborn	11
Edinburgh	1,334	Stratford / Marble Arch	6
Exeter	664		
Manchester	656	**Air travel**	**km**
Newcastle	920	Athens	4,770

York	682	Cape Town	19,100
		Hong Kong	18,980
Commuter journeys	**km**	Los Angeles	17,410
Chelmsford	100	Madrid	2,520
Guildford	90	Melbourne	34,020
Oxford	170	New York	11,070
Tonbridge	90	Paris	690
		Rome	3,140
		Tokyo	19,300

Appendix 8: An example of carbon audit feedback

When the carbon audit feedback below was distributed it was printed on two sides of paper.

Your Carbon Audit Feedback – Mr X

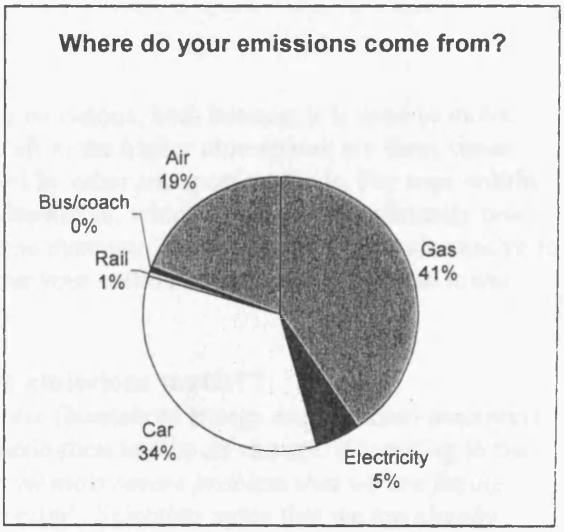
Tina Fawcett, University College London.
Email: t.fawcett@ucl.ac.uk, Phone: 01865 761697

Thank you!
Thank you very much for sending me the information for calculating your carbon dioxide emissions ('carbon emissions' for short). This brief document tells you what your personal emissions were in 2003, and shows you how this compares with the UK average. If after reading this you have any comments or follow-up questions, please feel free to get in touch and I'll do my best to help.

Your emissions and national averages
I have used the energy information you sent me to calculate your *personal* carbon emissions in kilograms of carbon dioxide, $kgCO_2$. If you live with other people I have allocated you a share of household carbon emissions (half if you are one of two people etc.). This figure is compared with UK average individual values calculated on the same basis.

	Your energy use and emissions, 2003		**UK average**
Category of energy use	**Energy used / distance traveled**	**Your personal carbon emissions ($kgCO_2$)**	***Personal carbon emissions ($kgCO_2$)***
Household gas	38,306 kWh	3,639	*1,480*
Household electricity	2,007 kWh	478	*870*
Car	15,373 km / 9,608 miles	3,075	*1,060*
Rail	442 km / 276 miles	48	*100*
Bus/coach	240 km / 150 miles	41	*90*
Air	3,400 km / 2,100 miles	1,757	*1,800*
TOTAL		**9,038**	***5,420***

Comments on your carbon emissions
- Overall your emissions are 67% higher than the average person in the UK.
- Your household gas usage is about two and a half times the average, but electricity use is less than average. Your overall personal household emissions are 75% higher than average.
- Your land transport was about two and a half times the average.
- Your air transport emissions were very similar to the national average.



The estimate of your carbon emissions is not entirely accurate because:

- An average value of carbon emissions per mile/km for cars has been used and your car may be considerably more or less fuel efficient than average

Nevertheless it is a good guide to where your carbon emissions come from and how you compare with the UK average.

General pointers for living a low carbon life

Household energy use
There are many ways of saving household energy, some of which are free and other which require investment. Simple measures include turning down the central heating thermostat by one degree, which can save around 10% of your heating energy. Energy saving light bulbs only use one quarter as much energy as normal bulbs and last ten times as long. Often energy companies and shops have special offers making the energy saving bulbs very cheap.

Unfortunately, I can't give you detailed advice on how to reduce your household carbon emissions, because I don't have details about your lifestyle or the efficiency of your house and your heating systems. To get further advice on household energy you can contact your local Energy Advice Centre – freephone number 0800 512 012. The advice centre can help you to complete a free 'home energy check' and then they will evaluate the efficiency of your home and guide you on making savings. They will also be able to advise you if there are any grants or discounts available in your area. Other good sources of advice will be your local city / district council and your energy company.

Travel on land
To reduce carbon emissions from travel on land the key advice is to make greater use of the zero emissions methods of travel – walking and cycling. This will also be good for your health. Public transport is generally somewhat better than travelling by car. Emissions *per person* from intercity trains and long distance coaches are about half those of an average car, but, perhaps surprisingly, city buses outside London have similar emissions to cars. London buses have somewhat lower emissions because they have higher passenger numbers per bus. Obviously there can be big differences between the fuel efficiency of different cars – and using a more efficient car will be cheaper as well more environmentally friendly.

Both using a lower energy method of travelling and trying to reduce the distance you travel are important for reducing carbon emissions. To alter your transport patterns you may first need to keep a travel diary and find out how and why you travel and where the opportunities are for change.

Travel by air
Air travel has particularly high associated carbon emissions, both because it is used to move long distances, and because emissions from aircraft in the higher atmosphere are three times more damaging than those emitted at ground level by other transport methods. For trips within the UK and to Europe there is the rail or coach alternative, which produce approximately one fifth of the emissions of a plane travelling the same distance. There is generally no alternative to air for long haul travel. If you are concerned about your carbon emissions and want to lower them, limiting your air travel should be a priority.

Why does reducing energy use and carbon emissions matter?

Carbon dioxide emissions from personal energy use (household energy and personal transport) make up one half of the UK's energy-related contribution to climate change. According to the government's chief scientist: "*climate change is the most severe problem that we are facing today - more serious even than the threat of terrorism*". Scientists agree that we are already seeing the effects of climate change in rising global temperatures, changing rainfall patterns, sea level rise and increased storminess. If we do not take action now to reduce our emissions, the consequences for ourselves and future generations will be serious at best and catastrophic at worst.

Sources for further information

www.est.co.uk / www.saveenergy.co.uk - government-backed web sites with lots of energy advice

www.guardian.co.uk/climatechange and www.newscientist.com/hottopics/climate – both good sites for general information and news stories about climate change

"How we can save the planet" by Mayer Hillman (with Tina Fawcett), Penguin Books, 2004

Finally, thank you again for your help with my research

Appendix 9: Full details of carbon audits

Two tables of data are presented. The first (Table A9.1) presents the original data collected on energy use and transport patterns from the case study individuals. The second table (Table A9.2) gives calculated values of carbon emissions per individual by fuel / transport mode.

Table A9.1: Data on energy use and transport patterns

		Household energy use (kWh)			Transport (km)								
						Rail			Bus / coach			Air	
Code	People /hh	Gas	Elec- tricity	Other fuels	Car	Intercity	Other	Under- ground	London bus	Other bus	Inter- city coach	Within Europe	Beyond Europe
1	2	1,615	4,288			128				5,440			
2	6	32,063	4,474			2,406		160		1,280		2,000	
3	2	14,441	1,709			5,972			450	270	7,650		
4	2	14,441	1,709		4,685	3,502				300	850		
5	1	0	4,800			3,000				500	1,000	1,200	
6	2	33,557	3,370 R		1,600	400	100	1,200	100	10			
7	2	20,733	1,779 R			3,456	320			912		4,160	
8	2	24,233	5,348		1,472		80	19	6			2,200	
9	1	9,801	1,464	10 kg Coal	14,400								
10	2	13,656	8,612		16,000 D		128				1,658		
11	2		26,434							1,760	288		
12	3	16,000	1,200 R			2,000		500	200		5,100	10,000	
13	1	9,882	1,662		9,600	1,920				16		4,186	
14	1	5,987	1,261		8,000						544	3,840	5,200
15	2	24,233	5,348		11,658		80	19	6			2,200	
16	1	211	7,660		16,694			240				1,034	
17	2	7,733	2,230		13,894	320				480	160	7,290	
18	1	7,040	1,747		14,400			80				1,300	7,469
19	1	20,958	3,000 R		3,200			200	50			6,900	
20	2	14,813	1,895			1,800		75	65			400	19,300
21	2	38,306	2,007		15,373	432		10		240		3,446	
22	3	31,346	7,486		1,600	26,400						6,504	
23	2		8,208	2581litres oil, 200kg coal	19,573								
24	4	15,629	6,125		18,400	800		80				9,000	
25	1		3,278			656	1,500	50	1,800			5,500	15,944
26	5	21,466	5,121		9,600	2,176				256		5,760	11,600
27	2	10,660	5,324			1,632		25		1,440		15,360	
28	1	21,524	1,580		7,200	912				416	1,632	3,000	12,100
29	3	42,315	13,000 R		14,400	800		160				3,000	19,100
30	2	10,834	3,279		12,800		112	16		112		19,200	
31	1	36,256	4,377		14,400	1,360	61	20	3	19		4,000	12,608
32	2	14,668	1,441			144					5,706	11,328	56,902

R = renewable electricity tariff, D = diesel car (otherwise petrol)

Table A9.2: Individual carbon emissions by household energy fuel and transport mode, kgC

Code	Individual carbon emissions (kgC)							
	Household energy use			Transport mode				
	Gas	Electricity	Other	Car	Rail	Bus/Coach	Air	TOTAL
1	42	279			4	252		577
2	277	97			75	59	278	787
3	374	111			179	190		855
4	374	111		256	105	32		878
5		624			90	45	167	926
6	869	0 (R)		87	39	3		999
7	537	0 (R)			118	42	579	1,276
8	628	348		80	4		306	1,366
9	508	190	2	785				1,485
10	354	560		611	6	36		1,566
11		1,718				88		1,806
12	276	0 (R)			70	116	1,391	1,853
13	512	216		524	58	1	582	1,892
14	310	164		436		12	988	1,910
15	628	348		636	4		306	1,921
16	11	996		911	5		144	2,066
17	200	145		758	10	26	1,014	2,152
18	365	227		785	2		833	2,212
19	1,086	0 (R)		175	4	1	960	2,225
20	384	123			55	2	1,740	2,304
21	992	130		839	13	11	479	2,465
22	541	324		87	792		905	2,650
23		534	1065	1,068				2,666
24	202	199		1,004	26		1,252	2,683
25		426			86	44	2,156	2,713
26	222	133		524	65	12	1,814	2,770
27	276	346			49	67	2,136	2,875
28	1,115	205		393	27	55	1,473	3,269
29	731	0 (R)		785	27		2,084	3,628
30	281	213		698	5	5	2,671	3,873
31	1,879	569		785	44	1	1,657	4,935
32	380	94			4	124	6,542	7,144

R = renewable electricity tariff

Appendix 10 – Household expenditure on energy

All the data in these tables come from the Expenditure and Food Survey 2002/03 (ONS 2003a).

Table A10.1 demonstrates that household expenditure on both motor fuels and domestic fuels increases with household income decile.

A10. 1: Weekly expenditure on motor fuels and domestic energy, by income decile, 2002/03

Houshold income decile	Expenditure per week per household (£)					Person/hh
	Motor fuels	Electricity	Gas	Other domestic fuels	All domestic fuels	
1	3.00	4.20	3.10	0.40	7.70	1.3
2	4.30	4.70	3.90	0.80	9.40	1.7
3	6.50	5.10	4.20	0.60	9.90	1.9
4	10.70	5.40	4.70	0.70	10.80	2.2
5	12.30	5.70	4.70	0.60	11.00	2.4
6	15.60	5.90	5.50	0.60	12.00	2.5
7	18.20	6.10	5.40	0.90	12.40	2.8
8	22.30	6.30	5.90	1.10	13.30	2.8
9	26.60	6.80	6.30	0.80	13.90	3.0
10	28.80	7.70	7.60	1.30	16.60	3.2

Table A10.2 demonstrates that individual expenditure on domestic energy is higher for those in lower income deciles than it is for those with higher incomes. It also shows that the percentage of income spent on domestic energy is highest for low income households – almost three times the percentage spent by decile 10 households. Conversely expenditure on motor fuels as of a percentage of the total rises with income decile.

A10. 2: Individual expenditure on motor fuels and domestic energy by income decile, 2002/03

Household income decile	Individual weekly expenditure 2002/03 (£)			Motor fuel as % of total	Domestic energy as % of total
	Motor fuels	Domestic energy	All expenditure		
1	2.31	5.92	106.00	2.2	5.6
2	2.53	5.53	98.40	2.6	5.6
3	3.42	5.21	114.40	3.0	4.6
4	4.86	4.91	134.80	3.6	3.6
5	5.13	4.58	140.80	3.6	3.3
6	6.24	4.80	157.40	4.0	3.0
7	6.50	4.43	161.60	4.0	2.7
8	7.96	4.75	192.20	4.1	2.5
9	8.87	4.63	213.60	4.2	2.2
10	9.00	5.19	274.40	3.3	1.9

Appendix 11: Lists of questions and comments raised at different meetings

All presentations except the first were carried out in conjunction with Dr Mayer Hillman. The names of questioners are noted where possible.

European Council for an Energy Efficient Economy, Summer Study 2003, 6 July 2003

Questions after presentation

Lloyd Harrison – what about the rest of the energy, how will that be controlled? Also, possibilities for cheating with, for example, business cars being used for personal travel.

Maarten Wolsink – difficulty of equity between countries. Can C&C ever really work given the huge drop in consumption people in the US would have to achieve? Different levels of reduction would be seen as unfair.

Woman from WWF – C&C is not the most promising basis for future negotiations. It is not being used in the current attempts to get the USA and Australia back on board with Kyoto. Even the NGOs have not agreed between themselves that C&C is the right position.

Paolo Bertoldi (European Commission) – this focus on carbon would not deal with the problem of nuclear energy. Under such a scheme nuclear would be favoured. It also ignores other aspects of sustainability and thus is too narrow in focus.

Francois Moisan (ADEME) – there is more than one definition of equity, giving equal carbon emissions quotas to everyone is not the only option. Economists have looked at other concepts of equity.

Jorgen Norgard – social equity could also be achieved by imposing high carbon taxes with rebates for the poor. This would be a much simpler scheme than introducing carbon rationing.

Steve Nadel (ACEEE)– what sort of exceptions to the rule of equal rations for all?

Neil ? (EST) – if this is going to be introduced, it would be a good idea to set the ration at a high level initially to make it acceptable to people.

Questions suggested by Heather Lovell (University of Cambridge PhD student)

- How would enforcement work?
- How would the system be administered?
- Who would be the people getting additional carbon rations, and why?
- Political will – is this feasible?
- Growth in population – how will this be handled under the rationing scheme?

- The balance between individual and institutional responsibility – this scheme gives all the responsibility to individuals, is that fair and can it be effective?

Comments made in seminar session about carbon rationing

- The individual responsibility entailed under this scheme fits with general changes in society towards individualisation of consumption.
- Rationing is a problematic name.
- Two questions can be separated: 1 - how could we get carbon rationing introduced?, 2 - would it work once implemented? Unless the answer to the second question is yes, there is little point in thinking about the first, so we need to answer the second question initially.
- The first step is for people to understand their own carbon footprint.
- Carbon is already going to be included on electricity bills under the new EU directive – this is a good start.
- Would the scheme have to be on a national or international scale? Which? Would it make any sense at a regional scale?
- The main objection seemed to be in terms of possible drop in GDP (or real economic progress indicator of choice). Thus to promote the idea it would be important to show that GDP would not necessarily be threatened.
- Developing countries do not necessarily consider themselves to be more vulnerable to climate change. The Indian argument is that climate change will be easier to cope with in their country where people are used to suffering, than it will be in the developed world.
- An alternative to carbon rationing (or massive carbon taxation) would be coping with climate change. In the short term this might be a more popular option.
- What would it take to get to the point where we make a decision between carbon rationing and carbon taxation?
- What will happen to the price of energy under this scheme – and does it matter?
- There should be more development of ESCOs under rationing – a good benefit.

Seminar attendees' advice on what research to do next:

- Show that rationing won't change GDP too much (qualitative arguments initially, then find a friendly economist to do the quantitative work)
- Look at areas of the economy that would benefit, e.g. for the UK, domestic tourism
- Must mention business and the economy when making the argument, even if you don't know what exactly you're proposing for them it is important to say something. Work out what this something is.

- Indicate what the world might look like under rationing – what would a family have to do to live within their ration, 5, 10, 20 years down the line?
- Identify other benefits of rationing, e.g. more ESCOs, less fuel poverty, etc.
- Look harder at EHCS energy and income data. Peter Iles thought BRE would be able to help with more data on this if necessary.

The Vaults, Oxford, 3 June 2004

- What is the future role of nuclear power?
- We already give power over to non-democratic decision-making bodies (e.g. EU has power over fisheries policy), so having a non-democratic institution bringing in carbon rationing could be possible.
- How will you persuade the government that they should take the actions you suggest?
- Carbon rationing doesn't fit with current political culture. It may well not be possible to get political consensus on this, because carbon rationing affects distribution of economic resources, which is at the heart of political difference.
- We can have a high standard of living without fossil fuel consumption. What we need is smaller-scale lifestyles in harmony with the earth.
- How can the threat of climate change be communicated to people without simply making them fearful?
- The government has strong links with the oil companies. How can individuals do anything given the power of corporate interests which are operating in the opposite direction?
- People are currently in denial about the importance of climate change, and persuading them otherwise will have to be a gradual process.
- How about banding electricity prices to penalise higher usage?
- Are there any other good examples of planned social change on this scale?
- What we need is a route map, telling us how we're going to get from where we are now to carbon rationing. Is more personal responsibility the first stage? What about the role of advertising and education?

Royal Institution, London, 14 June 2004

- What kind of society would it be if we have climate change and carbon rationing? What would our jobs be, how would we travel, what would our homes look like?
- Are you anti-development? Everyone should have opportunities to travel and develop their economies as we do in the west.
- It's not the planet that needs saving, it's our species' survival on the planet that is in question.

- The politics of carbon rationing seems very difficult. It's not possible to tell people there will be less jam tomorrow, you need instead to persuade them that it will be different jam. It is necessary to be descriptive of a better future.
- I don't believe in climate change, all the changes we have seen are natural.
- What political system could introduce carbon rationing? Can democracy survive?
- It will be very difficult to persuade the electorate to push for carbon rationing. Instead one should concentrate on educating the children, who will be the main sufferers, and get them to push for change.
- By the time we're really suffering from climate change, it'll be too late to do anything about it.
- Supermarket lorries are responsible for 40% of freight traffic- perhaps what we need are fewer choices of butter and fewer lorries.
- What we need is a single issue political party to push this issue forward.
- The role of big business is very important. They are increasingly dictating the agenda of government especially in the USA.
- If people are sceptical about the evidence on climate change (as one audience member was) they have to be very certain of their case, if they're wrong and persuade people they're right they will have blood on their hands.
- We need to be more imaginative about the political process - people need to move away from the consumer mindset.
- The redistributive aspect of carbon rationing will give poorer people more money and encourage the local economy to flourish.
- If carbon rations become a valuable commodity, what is there to prevent carbon wars breaking out in future?
- It is wrong to dismiss the possibilities of technology. The effort needed to implement a technology fix would be far less than altering the whole social and economic structure as called for by carbon rationing.
- Sometimes it seems that we'd do anything, even die, for our children and grandchildren, except turn the thermostat down.
- C&C and carbon rationing is not about redistribution, it's pre-distribution of what we need to do to save our children (Aubrey Meyer).

House of Commons, 15 June 2004

- There is no constitutional system available for implementing C&C - no institutions. (Richard Lamming)
- We need to start planning now for the next 30 years - is this happening anywhere? (Ross King, Brunel / Middlesex Uni)

- What we need to realise is that the eco-efficiency of quality of life is much more important and powerful than eco-efficiency alone. (Roger Levett)
- Need to bring concerns about climate change together with the understanding of what is currently happening to energy supplies. (David Fleming)
- We need also to consider the climate change aspects of material use (as well as energy use).
- What is the future role for nuclear energy?
- What would be the scale of resource transfer from North to South under C&C?

Meeting hosted by IPPR, 8 July 2004

- C&C is an attractive idea – but governments can't be forced to accept it.
- Some studies have show it should be possible to achieve radical cuts in CO_2 emissions with barely a dent in GDP. Would this be either good or possible?
- Would developing countries accept a cap on their emissions or aspirations?
- Why weren't markets mentioned in the talk – the solution to climate change will have to be market-led.
- Climate change could be seen as an opportunity. It gives the chance to replace the current energy infrastructure and energy systems. Climate change offers a chance to make things better.
- Need to tackle the short term issues in policy as well as the long term issues such as climate change.

Appendix 12: A strategy for further investigation of carbon rations

This appendix sets out, in more detail than Chapter 7, how further investigations of individual carbon emissions and the effects of rationing could proceed.

Developing the methodology for calculating individual carbon emissions

This thesis used a deliberately simplified methodology with which to estimate individual carbon emissions. However, to get more precise information on individual carbon emissions it would be necessary to develop the methodology further. A number of questions would have to be decided:

- Whether respondents need to keep travel diaries, and if so for how long
- How to accurately capture data on annual air travel
- How to include people who move house during the previous year, or who don't have a record of annual energy bills
- How to involve children
- What to do about using actual carbon emissions figures for cars, where available, and what figures to use when they are not available
- Whether to try to include carbon emissions for car passengers as well as car drivers
- Including travel via taxis, motorcycles and mopeds
- Generating very clear guidelines about the difference between personal and business travel
- Creating guidelines from how to determine household energy use where people work from home
- Do further research on Hillman's initial figures for the carbon emissions from travel by sea
- How and whether travel in foreign countries, e.g. by train, car or bus, is to be included.

How some of these issues are addressed will also depends on the mechanism for collecting the data and how accurate the results need to be.

Large-scale survey of current individual carbon emissions

Chapter 6 presented pilot data on individual carbon emissions. However, a much better understanding of the variations in carbon emissions between individuals and households would be essential before carbon rationing could be introduced. There are existing government surveys which cover some of the activities which lead to personal carbon emissions. Presently, data on household and personal transport energy use is collected by different government departments – with ODPM (the Office of the Deputy Prime Minister) taking responsibility for housing surveys and Department for Transport commissioning national travel surveys. Domestic energy use is recorded for the whole household, because energy use is shared across all members of the household and an allocation to the different individuals in the household would make little sense for most purposes. The key household energy studies have been the English House Condition Energy Surveys (e.g. (DETR 2000). Travel data is recorded via the National Travel Survey, which provides information on personal travel and changes in travel patterns over time in Great Britain (DfT 2004). This does not include international travel. Travel abroad is monitored by the International Passenger Survey, a survey of a random sample of passengers entering and leaving the UK by air, sea or the Channel Tunnel, which is run by the Office for National Statistics (ONS 2003).

The carbon emissions survey would need to cover the whole of the UK, not just England or Great Britain, as is the case with existing energy surveys. The National Travel Survey as the basis for a carbon emissions survey has some advantages because it already asks for travel diaries and includes children in its sample. However, adding questions about international travel in the previous year, and including household energy use questions would add to the complexity of the survey. Whether it would be better to have a completely new survey, or to adapt one of the existing ones is a practical and administrative question which those managing the current surveys are best placed to answer.

It would also be worthwhile beginning a longitudinal sample, showing how the same people's emissions change over time. In addition, it might be possible to do a retrospective longitudinal study for a few years into the past with people who have kept energy bills and MOT certificates for cars. This is unlikely to be as accurate as a contemporaneous study, but it could give useful early insights into the variability of personal carbon emissions over time.

The data from a nationally-representative survey would be used to advance the understanding of carbon emissions from different groups within society. Some of the topics which could be investigated with such data are:

- Determine the position of potentially disadvantaged groups under carbon rationing, e.g. one-person households, people living in rural areas
- Discover whether people's emissions can be fitted into characteristic patterns, for which different advice on carbon reduction possibilities would be required.
- One of the key questions is what ration children would be given. The data from the national questionnaire should help elucidate this For example, it might be that graduated rations at different ages, say for 0-5, 6-10, and 11-15 and then children of 16+

receiving an adult ration – but this would depend on what difference children make to household energy and travel patterns.

Current work on carbon audits

The author is aware of two possible projects which are aiming to use carbon audits as a starting point for working with householders to reduce their carbon emissions and other environmental impacts (NEF 2004, Marshall 2004). In addition, Anderson and Starkey are planning to carry out some similar work with individuals using DTQs as a basis (2004). This is clearly worthwhile research, although, attempting to reduce one's personal carbon emissions in today's world will be a very different experience than attempting the same in a world where carbon rations were mandatory and social and economic infrastructures were oriented towards carbon saving.

Household energy use by single householders

Independently of further research on carbon emissions, research should be carried out to understand in more detail the domestic energy consumption of one-person households. Is this chiefly a function of the house size, i.e. are their houses about the same size as those of multi-person households, or is it because of their energy 'fixed costs' cannot be shared across several people? In addition, how much variation does the national average figure hide? It might be possible to do some of this research using the full database from the most recent EHCS Energy Survey (DETR 2000).